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DOCUMENTATION OF THE AFGL STATISTICAL ANALYSIS PROGRAM (ASAP) FOR THE GLOBAL MULTIVARIATE ANALYSIS OF HEIGHTS AND WINDS

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The AFGL global multivariate analysis of the geopotential height and wind is described in detail. The purpose of this documentation is to probe the missing links between previously published accounts and the actual FORTRAN code.

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1. Introduction

The multivariate analysis of heights and winds is one of the key ingredients of any global data assimilation system (GDAS), e.g., McPherson et al. (1979), Lorenc (1981). The AFGL GDAS has been under development at AFGL/LYP for several years. In many respects, it parallels the NMC GDAS. A GDAS contains three main components: a forecast model, an analysis method and an initialization procedure. ~~Here we~~ This document discusses only one part of the analysis method, namely, the multivariate statistical analysis of height and wind. Currently, the AFGL GDAS analyzes moisture in a separate program and does not analyze surface or sea level pressure.

This documentation does not attempt to provide an overview of the entire AFGL GDAS or even of the entire height-wind analysis. These are provided by Norquist (1986b). ~~Our~~ The author's purpose ~~here~~ is to describe the detailed workings of the height-wind analysis program ASAP1. Keywords: numerical weather prediction; optim

interpola

Fortran

Subrout

The notation used in this documentation does not directly mirror the FORTRAN symbolic names used in the program. Identification between the documentation notation and the symbolic names of global variables (i.e., those in common blocks) is made in Section 2. Other key symbolic names are identified or defined as they are used. Throughout sections 2 through 4, I use the following notation:

The letters u, v and z will denote, respectively, the eastward wind component (m/s), the northward wind component (m/s) and the height of a pressure or sigma surface (m). Upper-case letters (U, V, Z) without any circumflex are reserved for observations. Upper-case letter with the (~) circumflex ($\tilde{U}$, $\tilde{V}$, $\tilde{Z}$) are reserved for analysis or first guess (i.e., forecast) values. The residuals are identified by lower-case letters (u, v, z). For example, $u = U-\tilde{U}$. The letters ℓ and k will be reserved for vertical indices. The letter k is preferred for sigma layer variables, e.g., T_k is the observed temperature (presumably interpolated) at sigma layer k. To distinguish quantities at sigma layers from those at sigma levels, I will put a circumflex (^) over the first character of the subscript of a sigma level quantity, e.g., $\tilde{T}_{\hat{k}}$ is the first guess temperature at sigma level k. There are two reasonable ways of numbering the sigma levels; unfortunately, both are used in ASAP1. First of all, all vertical indices increase with increasing altitude (and decreasing pressure). Usually, the pressure at the kth sigma

level is the pressure at the bottom of the kth sigma layer. Thus, $\tilde{P}_{\hat{1}} = \tilde{P}_*$ the forecast surface pressure. For height Z, the indices are usually offset by one; the height at sigma level k is the height of the top of the kth sigma layer. Thus $\tilde{Z}_{\hat{0}} = Z_*$, the topographic height. Sigma level usage will be defined as it is used throughout this documentation. The letter ℓ will be preferred for pressure levels or layers. Usually, data is associated with pressure levels; usually, a circumflex will not be used to distinguish pressure levels from layers. Lower-case letters used as indices will normally range from 1 to some maximum value, which will be denoted by the corresponding upper-case letter. Thus, $\tilde{T}_k$, k=1,K is the set of first guess temperatures at the sigma layers. Pressures associated with observations will be denoted P, pressures associated with the first guess of the observations evaluated in sigma coordinates will be denoted $\hat{P}$, pressures associated with a residual will be denoted p, and mandatory levels will be denoted $\tilde{P}_\ell$. For example, first guess layer pressures are $\tilde{P}_k$.

In this documentation, an observation is the collection of all data observed at a particular (λ,ϕ) location. Data or residuals are individual pieces of information. Except during the actual update, a (u,v) horizontal wind is considered a single piece of information.

Tables 1 and 2 summarize the above discussion and list other commonly used notation.

Table 1. Variables and their definitions

Variable	Definition
(U,V)	observed horizontal wind (m/s)
Z	observed height of pressure or sigma surface (m)
P	observed pressure (i.e., pressure of an observation before interpolation) (mb)
$(\tilde{U},\tilde{V})$, $\tilde{Z}$, $\tilde{P}$	forecast (first guess) or analyzed values. $\tilde{P}$ may also denote the pressure of an interpolated observation. These variables refer to observation locations while the data is read and prepared, but to analysis locations during the actual update.
$(u,v),z$	residuals of $(U,V),Z$
p	pressure associate with residuals
T	temperature (Kelvin or Celsius)
R	relative humidity (percent)
Q	specific humidity
$\tilde{T}$, $\tilde{R}$, $\tilde{Q}$	first guess values of (T, R, Q)
t, r, q	residuals of (T, R, Q)
X	generic variable, which may be any one of the above
λ	longitude
ϕ	latitude
σ	sigma, the normalized vertical coordinate defined by p/p^*
$E(X)$	standard deviation of X
E_p	prediction error
E_o	observation error
B	buddy check box
<u>dsi</u>	data source index
<u>type</u>	data type (<u>dsi</u>/10)
$Q(X)$	quality mark associated with X
$Q_I(X)$	quality indicator associated with X
$Q_L(X)$	quality level associated with X
	Q_I are the quality control flags in the Level II data sets. Q are the generic quality marks translated from the Q_I which are used in data selection. Q_L are the adjusted Q which are used in the buddy check flagging procedure. (See Section 5.2.)
μ	horizontal correlation
ν	vertical correlation
ρ	total correlation
ϵ	normalized observation error
$\bar{P}$	mandatory pressure (mb)

Table 2. Subscripts and their usage

Subscripts	Usage
i, j, n, m	generic, usually used for observation indices and pointers
k, ℓ	layer/level indices. k is preferred for σ layers/levels, ℓ is preferred for p layers/levels. The (^) circumflex denotes a sigma level.
u	the underground layer/level
*	the surface
g	the particular grid point under consideration. (Either (λ,ϕ) or (λ,ϕ,k).)
ℓ_a, ℓ_b	layer/level above, below
ℓ_u, ℓ_ℓ	upper, lower layer/level

2. Global Variables

The variables stored in common blocks are described here, common block by common block, in alphabetical order. If more than one symbolic name is listed on one line, then the different names are used in different subroutines.

Name: AS140 (common block)

Contents: Locations and associated variables of observations and the current grid point, and the list of observations selected for the analysis at the current grid point

Author: D. Norquist, SASC, 1980 - 1986

Documentation: R. Hoffman, AER, 1986

Referenced by: ASAP1, ASAP2

Initialized by: none

Symbolic name	Meaning
YLG	ϕ_g, grid point latitude (degrees)
XLG	λ_g, grid point longitude (degrees)
MF	m_g, map factor
XGG	x_g, grid point coordinate, stereographic projection
YGG	y_g, grid point coordinate, stereographic projection
FIHG	+ (or −) 1 for a grid point in the Northern (or Southern) Hemisphere
NGBX,NGBOX	N_B, number of observations in a box or selected for analysis
NAKEY(i)	list of observations selected, i=1, N_B, < NSNDS
NWORDS	1 + 5K + $2K_r$, second dimension in OBD array in /RESID/
QLAT(n)	list of ϕ_n, observation latitudes
QLON(n)	list of λ_n, observation longitudes
JDSI(n)	list of $\underline{dsi}_n$, observation data source indices
ABYLG	$\lvert\phi_g\rvert$, absolute value of grid point latitude (degrees)
YGRAD	ϕ_g, grid point latitude (radians)
XGRAD	λ_g, grid point longitude (radians)

Name: AS1AS2 (common block)

Purpose: Contains constants and variables for the models of the statistical quantities. Other constants are hardwired in ESOBER.

Author: D. Norquist, SASC, 1980 - 1986

Documentation: R. Hoffman, AER, 1986

Referenced by: ASAP1, ASAP2, FLAGS

Initialized by: ASAP1

Symbolic name	Meaning
PM(ℓ)	$\overline{P}_\ell$, mandatory pressures, ℓ=1, 12 (1000, 850,...50 mb)
ZER	limit on z corrections (250 m)
WER	limt on wind corrections (25 m/s)
KH(i)	k_h, horizontal forecast error correlation constants, i = 1,3 ((2, 1.5, 1) x E-12m^{-2})
KP	k_p, vertical forecast correlation constant (5.0)
DRAD	$\pi/4$
ERAD	$7\pi/4$
KHO	k_{h0}, horizontal observational error correlation constant (11.3 E-12m^{-2})
KPO	k_{p0}, vertical observational error correlation constant (8.3)
KPOW	k^w_{p0} , vertical observational error correlation constant for winds (3.2)
OMEGA	Ω, rotation rate of the earth (7.29116E-5 sec^{-1})
NUKPOS	look up table for satellite height vertical observational error correlations (Norquist 1986b, Table 3)
EPZ	$E_p(\tilde{Z}_\ell)$, EPE (estimated prediction error) for heights at mandatory layers for this latitude (also used for $E_{a0}(Z_k)$)
EPU	$E_p(\tilde{U}_\ell)$, EPE for u wind component at mandatory layers for this latitude

EPV	$E_p(\tilde{V}_\ell)$, EPE for v wind component at mandatory layers for this latitude
IFRST	= 1 if this is the first (or 0 if this is not the first) analysis in a sequence
ZPEGR	$E_{\Delta T}(\tilde{Z}_\ell)$, prediction error growth for a 6 h period at mandatory levels
ZAEL	$E_\infty(\tilde{Z}_\ell)$, analysis error limits at mandatory levels
SGTW	$E_T(\tilde{U}_\ell)$, tropical wind EPE at mandatory levels

Name: CCONST (common block)

Purpose: Contains constants describing the analysis and fine mesh grids as well as some other dimensional constants.

Author: D. Norquist, SASC, 1980 - 1986

Documentation: R. Hoffman, AER, 1986

Referenced by: ASAP1, ASAP2, FG, FLAGS, SETFG

Initialized by: ASAP1

Symbolic name	Meaning
MG	number of longitudes in fine mesh grid (360)
NG	number of latitudes in fine mesh grid (181)
NXG	number of longitudes in analysis grid (61)
NYG	number of latitudes in analysis grid (62)
A	A_e, radius of earth (6.371 E6 m)
MANDLVL	number of mandatory pressure levels (12)
NSNDS	M_{max}, maximum number of observations to select (8)
NLRHS	maximum number of pieces of data to select (10)
DLAT	$\Delta\phi$, latitude increment for the fine mesh grid (1°)
DLON	$\Delta\lambda$, longitude increment for the fine mesh grid (1°)

Name: DCONST (common block)

Purpose: Contains physical constants, dimensional constants and the missing value indicator.

Author: D. Norquist, SASC, 1980 - 1986

Documentation: R. Hoffman, AER, 1986

Referenced by: ASAP1, ASAP2, CALCRES, CNTOBS, FG, FLAGS, LOWTMP, LOWTMPS, MASTOR1, MASTOR2, MASTOR4, MASTOR6, POINTS, PTOSIG, SATLTMP, SETFG

Initialized by: ASAP1

Symbolic name	Meaning
ML,IML	K, number of model/analysis sigma layers (12)
PI	π (3.1415926536)
DNN	missing value indicator (-999.9)
G,GRAV	g, acceleration of gravity (9.8 m/s)
R,RG	R, gas constant for air (287.05 J kg^{-1} K^{-1})
CP	C_p, specific heat of air (1005 J kg^{-1} K^{-1})
RKAPPA	R/C_p
RK1	$R/C_p + 1$
MLP1,KPP1	K + 1, number of sigma levels (13)
EPS	molecular weight of air/molecular weight of water (1/0.622)
MLRH	K_r, number of sigma layers at which humidity is analyzed (7)
LLL	1 + 5K, number of words in a dry profile (see /RESID/)

Name: DEL (common block)

Purpose: Contains the residuals for single level data as calculated by CALCRES.

Author: D. Norquist, SASC, 1980 - 1986

Documentation: R. Hoffman, AER, 1986

Referenced by: CALCRES, MASTOR2, MASTOR6

Initialized by: none

Symbolic name	Meaning
DELT	t, temperature residual
DELU	u, u-wind component residual
DELV	v, v-wind component residual
DELZ	z, height residual

Name: FGDATA (common block)

Purpose: Contains values of the first guess fields evaluated at the current observation location. These values are obtained by interpolating a fine mesh (1° x 1°) grid bilinearly in λ and ϕ (see subroutine FG).

Author: D. Norquist, SASC, 1980 - 1986

Documentation: R. Hoffman, AER, 1986

Referenced by: CALCRES, FG, MASTOR1, MASTOR2, MASTOR4, MASTOR6, PTOSIG, SATLTMP

Initialized by: none

Symbolic name	Meaning
ZO(k)	$\tilde{Z}_{\hat{k}}$, heights at $\sigma_{\hat{k}+1}$
TO(k)	$\tilde{T}_k$, temperatures at σ_k
UO(k)	$\tilde{U}_k$, u wind component at σ_k
VO(k)	$\tilde{V}_k$, v wind component at σ_k
RHO(k)	$\tilde{R}_k$, relative humidity at σ_k

Name: FGFLDS (common block)

Purpose: Contains two latitudes of the 1° x 1° fine mesh grid used to evaluate the first guess at the observation locations.

Author: D. Norquist, SASC, 1980 - 1986

Documentation: R. Hoffman, AER, 1986

Referenced by: FG, SETFG

Initialized by: none

Symbolic name	Meaning
TG (i,j,k)	$\tilde{T}(i,j,k)$, temperature, k=1,K
UG (i,j,k)	$\tilde{U}(i,j,k)$, u-wind component, k=1,K
VG (i,j,k)	$\tilde{V}(i,j,k)$, v-wind component, k=1,K
RHG (i,j,k)	$\tilde{R}(i,j,k)$, relative humidity, $k=1,K_r$
PSG (i,j)	$\tilde{P}_*(i,j)$, surface pressure
ZSG (i,j)	$Z_*(i,j)$, model topography

Note: In all of the above, i=1,...,360 indexes the longitude $\lambda_i=i-1$ and j=1,2 indexes the two latitudes currently in memory.

Name: IFLG (common block)

Purpose: Contains flag arrays used in subroutine FLAGS to perform buddy check. Maximum number of observations to be checked in a box is currently 100.

Author: D. Norquist, SASC, 1980 - 1986

Documentation: R. Hoffman, AER, 1986

Referenced by: FLAGS

Initialized by: none

Contents:

Symbolic name	Meaning
IFZTI	${}^{z}F_{i}^{j}$
IFZTJ	${}^{z}F_{j}^{i}$
IFWI	${}^{w}F_{i}^{j}$
IFWJ	${}^{w}F_{j}^{i}$

See FLAGS(0) for a detailed discussion.

Name: LOWT (common block)

Purpose: Contains constants needed to apply Flattery algorithm to convert layer-layer temperatures to sigma layer temperatures.

Author: D. Norquist, SASC, 1980 - 1986

Documentation: R. Hoffman, AER, 1986

Referenced by: LOWTMP

Initialized by: ASAP1

Contents:

Symbolic name	Meaning
AL, AC	w_L
BL, BC	w_U
AT	A^T
ATA	$(A^TA)^{-1}$

Refer to Appendix A of Norquist (1986b, pp. 55-58) for details.

Name: RESID (common block)

Purpose: Contains the residuals calculated by the MASTORn routines.

Author: D. Norquist, SASC, 1980 - 1986

Documentation: R. Hoffman, AER, 1986

Referenced by: ASAP1, ASAP2, CONTOBS, FLAGS, MASTOR1, MASTOR2, MASTOR4, MASTOR6, POINTS

Initialized by: none

Contents:

Symbolic name	Meaning
OBD (n, ℓ)	contains information for observation n=1,6000. The various residuals are indexed by ℓ. They are stored in the order: p_*, $[\hat{z}_k$, $Q(\hat{z}_k)$, u_k, v_k, $Q(u_k,v_k)$, $k=1,K]$, $[r_k$, $Q(r_k)$, $k=1,K_r]$. Thus $\ell=1$, $1+5K+2K_r = 1,75$.

Name: SIGK (common block)

Purpose: Contains variables describing the vertical structure of the model.

Author: D. Norquist, SASC, 1980 - 1986

Documentation: R. Hoffman, AER, 1986

Referenced by: ASAP1, ASAP2, FG, FLAGS

Initialized by: none

Symbolic name	Meaning
SIGMA(k), SL(k)	σ_k, k=1,K, sigma in layer k
SLU	σ_u, sigma in underground layer
SI(k)	$\sigma_{\hat{k}}$, k=1,K+1, sigma at interface at bottom of layer k

Name: UADATA (common block)

Purpose: Contains data as read in by MASTORn routines from GWE Level II data sets. Usage varies with context. E.g., in MASTOR1 Z_ℓ is the height at P_ℓ, while in MASTOR4 it is the height relative to Z_1 of P_ℓ.

Author: D. Norquist, SASC, 1980 - 1986

Documentation: R. Hoffman, AER, 1986

Referenced by: MASTOR1, MASTOR2, MASTOR4, MASTOR6, PTOSIG

Initialized by: none

Symbolic name	Meaning
$P(\ell)$	P_ℓ, ℓ=1,90, observed pressure
$Z(\ell)$	Z_ℓ, ℓ=1,90, observed height associated with P_ℓ
$T(\ell)$	T_ℓ, ℓ=1,90, observed temperature associated with P_ℓ
$U(\ell)$	U_ℓ, ℓ=1,90, observed u-wind component associated with P_ℓ
$V(\ell)$	V_ℓ, ℓ=1,90, observed v-wind component associated with P_ℓ
$Q(\ell)$	Q_ℓ, ℓ=1,90, observed specific humidity associated with P_ℓ
$IQZ(\ell)$	$Q(Z_\ell)$, ℓ=1,90, quality mark or indicator associated with Z_ℓ
$IQT(\ell)$	$Q(T_\ell)$, ℓ=1,90, quality mark or indicator associated with T_ℓ
$IQW(\ell)$	$Q(U_\ell,V_\ell)$, ℓ=1,90, quality mark or indicator associated with (U_ℓ,V_ℓ)
$IQQ(\ell)$,$IQCQ(\ell)$	$Q(Q_\ell)$, ℓ=1,90, quality mark or indicator associated with Q_ℓ

Name: UASIGMA (common block)

Purpose: Contains the observations and their associated quality marks interpolated to model sigma layers/levels.

Author: D. Norquist, SASC, 1980 - 1986

Documentation: R. Hoffman, AER, 1986

Referenced by: CALCRES, MASTOR1, MASTOR2, MASTOR4, MASTOR6, PTOSIG

Initialized by: none

Symbolic name	Meaning
ZBO(k)	$\hat{Z}_k$, k=1,K, height at $\hat{\sigma}_{k+1}$
TBO(k)	T_k, k=1,K, temperature at σ_k
UBO(k)	U_k, k=1,K, u-component wind at σ_k
VBO(k)	V_k, k=1,K, v-component wind at σ_k
QBO(k)	Q_k, k=1,K_r, specific humidity at σ_k
IQZO(k)	$Q(\hat{Z}_k)$, k=1,K, quality mark associated with $\hat{Z}_k$
IQTO(k)	$Q(T_k)$, k=1,K, quality mark associated with T_k
IQWO(k)	$Q(U_k,V_k)$, k=1,K, quality mark associated with (U_k,V_k)
IQQO(k),IQCQO(k)	$Q(Q_k)$, k=1,K_r, quality mark associated with Q_k

3. Program Units

The main program ASAP1 and the various subprograms it involves are described here in alphabetical order. Within each description, there are various numbered subsections. The start of each of these blocks is identified by a comment card in the FORTRAN code.

Name: ASAP1 (main program)

Purpose: Performs the statistical analysis procedure following Bergman (1979) and Dey and Morone (1985) as described in Norquist (1982, 1983, 1984, 1986a, 1986b) and Halberstam et al. (1984). The moisture analysis is now separate but moisture residuals are calculated here for the GWE Level II data and stored with their associated identification and location parameters on units 8 and 3. ASAP1 calls several routines to read in the data, interpolate to sigma coordinates, and perform quality control. It then loops over all the analysis grid points, selecting observations and calling ASAP2 to actually perform the analysis. Note then an observation may be an entire RAOB report or a single level AIREP. The RAOB contains many pieces of data, the AIREP only one.

Author: D. Norquist, SASC, 1980 - 1986

Documentation: R. Hoffman, AER, 1986

Referenced by: None

References: ASAP2, CNTOBS, FLAGS, MASTOR1, MASTOR2, MASTOR4, MASTOR6, POINTS, SETFG.

Commons used: AS140, AS1AS2, CCONST, DCONST, RESID, SIGK

Arguments: None

I/O units: 2, 3, 7, 8, 10, INPUT, OUTPUT

Description:

(1) Initialize constants.

(2) Read in namelist containing variables describing date and time and whether this is the first analysis in a sequence.

(3) Open unit 2, the unpacked GWE Level II data set, described by Norquist (1984, p. 17-33) and check header record date/time against that read via namelist (2).

(4) Set up the vertical structure in /SIGK/. (See Section 5.4.)

(5) Read in type 1 data (RAOBS) from file 2 on unit 2 (MASTOR1). In (5) - (8) the call to SETFG initializes the horizontal interpolation procedure.

(6) Read in type 4 data (SATEMS) from file 5 on unit 2 (MASTOR4).

(7) Read in type 2 data (AIREPS) from file 3 on unit 2 (MASTOR2).

(8) Read in type 6a data (SATWINDS) from file 7 on unit 2 (MASTOR6).

(9) Count valid data read in and display totals (CNTOBS).

(10) Gross and buddy check data (FLAGS), assign points to each observation (POINTS). These points will be used in the observation selection procedure. Count remaining data and display totals (CNTOBS).

(11) Store residuals on unit 8 and identification/location parameters on unit 3.

(12) Beginning of analysis phase [(12) - (27)]. Select tropospheric value of k_h (2.0E-12 m^{-2}) given by Dey and Morone (1985). (See (23).) Begin loop over all latitudes in the analysis grid.

(13) Determine ϕ_g, the latitude of the current grid row. The sine of ϕ_g is read from unit 7 if Guassian latitudes are used (ITLAT = 1), otherwise regularly spaced ϕ_g are used. (Currently ITLAT is hard-wired to 1.)

(14) If this is the first analysis in a sequence read in the standard estimated prediction errors (EPE) at the mandatory levels from unit 10. In this case the EPE, $E_p(\tilde{Z}_\ell)$, $E_p(\tilde{U}_\ell)$, $E_p(\tilde{V}_\ell)$ do not depend on longitude.

(15) Begin loop over all longitudes. Define λ_g.

(16) If $|\phi_g| > 70$, convert (λ_g, ϕ_g) to (x_g, y_g) the coordinates in a polar stereographic projection true at the pole. (See Section 5.5.)

(17) Define the latitude/longitude observation selection box. The box is $\pm$ 15° in latitude and $\pm$ 30° in longitude if $|\phi_g| < 60°$. (Longitude window would be $\pm$ 40° if $k_h < 1.8$ E − 12 m^{-2}, but this will not occur for current parameter settings.) For $|\phi_g| > 60°$ all longitudes will be considered. (See (20) below.)

(18) Begin data selection phase [(18) − (25)]. (See Norquist 1986b, pp. 9–10.) Set μ^{zz}_{min} to 0.1. Start loop on data type, NTY = 1, 2, 3, 4, which correspond to type = 1, 4, 2, 6a. If M_{max} (i.e. NSNDS) observations have been selected exit loop. Begin loop on observations within this type. This algorithm implies that if M_{max} type 1 observations are found with $\mu^{zz} > \mu^{zz}_{min}$ other data types are not considered, but all the type 1 observations are considered. Similarly for type 1 and 4 combined, type 1, 4, and 2, combined, etc.

(19) Check that ϕ_n is within the selection box. If not make use of fact that data are sorted by latitude. If ϕ_n is south of box go to end of observation loop. If ϕ_n is north of box go to end of type loop.

(20) If $|\phi_g| < 60$, check that λ_n is within the selection box. If not go to end of observation loop. Note the check when the box straddles Greenwich, i.e. when $\lambda_{max} < \lambda_{min}$. In this case $\lambda_{max} < \lambda_n < \lambda_{min}$ implies λ_n is not in the box.

(21) If $|\phi_g| > 70$ then transform observation location (λ_n, ϕ_n) to polar stereographic projection coordinates (x_n, y_n) and calculate d_{gn} the distance between the grid point and the observation.

(22) Else if $|\phi_g| < 70$ then calculate distance with approximate great circle formula (Schlatter, 1975).

$$d_{gn}^2 = a^2[(\cos(\bar{\phi})\,\Delta\lambda)^2 + (\Delta\phi)^2]$$

(23) Calculate horizontal correlation $\mu_{gn}^{zz} = \exp(-k_h d_{gn}^2)$. If the number of observations selected, $M < M_{max}$ skip observations with $\mu < \mu_{min}$. If $M > M_{max}$, skip observations with $\mu^* < \mu^*_{min}$. Here * indicates that μ has been multiplied by the number of points assigned to the observation in (10).

(24) Insert the current observation in the list of observations for this analysis point stored in descending μ^* sort order. If M was already M_{max}, drop the last one in the list and reset μ^*_{min}. If M was $M_{max} - 1$, set μ^*_{min} to the last μ^* in the list. The list is maintained in two arrays: NAKEY(m) = n, which points to the observation arrays and MUTTXY (m) = μ^*_n.

(25) End of data selection loops on observation and <u>type</u> (18).

(26) Apply statistical interpolation procedure. (ASAP2).

(27) End of loops over analysis longitudes (15) and latitudes (12).

(28) End of main module.

Name: ASAP2 (subroutine)

Purpose: Performs update of all variables $(\tilde{Z},\tilde{U},\tilde{V})$ at all sigma layers for a single (λ_g,ϕ_g) grid location. The procedure follows that of Dey and Morone (1985) and Bergman (1979) as described by Norquist (1986b, pp. 10–18).
In brief, ASAP2 obtains (a) the first guess values and (b) the expected prediction errors at the analysis point. Then, for each layer, including a subsurface layer, ASAP2 (c) selects observations highly correlated with the grid point variables, (d) calculates the observation location-grid point prediction error correlations for the selected observations (i.e., the r.h.s. of the normal equation), (e) calculates the matrix of observation location-observation location prediction and observational error correlations (the same matrix is used for $\tilde{Z}$, $\tilde{U}$ and $\tilde{V}$), (f) solves the normal equations for the nondimensional analysis weights and (g) calculates the corrections and expected analysis errors. Finally, (h) z corrections are converted to T corrections, and the first guess is updated and stored along with the corrections and estimated analysis errors.

Author: D. Norquist, SASC, 1980 - 1986

Documentation: R. Hoffman, AER, 1986

Referenced by: ASAP1

References: CHLSKY, ESGBER, LOWTMP, RECALC

Commons used: AS140, AS1AS2, CCONST, DCONST, RESID, SIGK

Arguments:

IGP	λ_g index
JGP	ϕ_g index
IMON	month of the analysis

I/O units: 4, 6, 10, 11, OUTPUT

Description: Subscript and pointer usage in ASAP2 are more complicated than elsewhere:

Symbolic name	Meaning	
IN, JN	i, j	index piece of data which is used in analysis
NVI, NVJ	$D_T(i)$	data type (1,2,3) = (z,u,v) or (1,2) = (z,(u,v))
NN	$m(i)$	intermediate pointer to n and ℓ once $D_T(i)$ is known
NI, NJ	$n(i) = n(m(i),D_T(i))$	observation index within local array
LI, LJ	$\ell(i) = \ell(m(i),D_T(i))$	layer/level index
ZB(NI,LI), etc.	$x(i) = x(\ell(i),n(i),D_T(i))$	is the value of the ith datum. It is stored in one of three arrays for z, u and v separately, depending on the value of $D_T(i)$
PH(NI,LI), etc.	$p(i) = p(\ell(i),n(i),D_T(i))$	is the value of pressure associated with the ith datum. It is stored in one of two arrays for z and (u,v) separately, depending on the value of $D_T(i)$
E	expected standard deviation, e.g.,	
	$E_p(\tilde{Z}_k)$	EPE of the first guess
	$E_a(z_{kg})$	EAE (becomes $E_{a0}(\tilde{Z}_k)$)
	$E_{a0}(\tilde{Z}_k)$	EAE of previous forecast
	$E_0(u_{\ell n})$	EOE

(a) = (1) - (2) Obtain the first guess values

(1) From <u>unit</u> = 4, read in first guess values ($\tilde{T}_k$, $\tilde{U}_k$, $\tilde{V}_k$, $\tilde{P}_*$) for current location. Compute $\tilde{P}_k$ and $\tilde{P}_u$. Here and below the subscript u denotes the underground layer.

(2) Calculated G_g, the coefficient of geostrophy at the grid point. (See Norquist 1986b, p. 14 and Section 5.6.)

(b) = (3) - (7) Determine the expected prediction errors (EPE).

(3) Begin determination of EPE (expected prediction errors). If this is the first analysis in a sequence (IFRST = 1), then use the a priori NMC values interpolated linearly in $\ln p$ to the sigma layer pressures $\tilde{P}_k$. Above 50 mb, the 50 mb value is used, below 1000 mb extrapolation is used. Since the NMC values do not depend on λ_g they are read outside the longitude loop in ASAP1(14) and stored in /AS1AS2/. The EPE values $E_p(\tilde{Z}_k)$, $E_p(\tilde{U}_k)$, $E_p(\tilde{V}_k)$ are stored in variable EPE. Note that $E_p(\tilde{Z}_k)$ is the EPE of $\tilde{Z}$ at σ_k not at $\sigma_{\hat{k}+1}$ (see (7)).

(4) Otherwise, if this is not the first analysis in a sequence (IFRST = 0), then:

From <u>unit</u> = 10, read $E_{a0}(\tilde{Z}_k)$, the expected analysis error of the previous analysis. Interpolate $E_{\Delta T}(\tilde{Z}_k)$ the EPE growth during the interval between analyses from the mandatory layer values of Dey and Morone (1985, Table 3, p. 309). Also interpolate $E_\infty(\tilde{Z}_k)$, the climatological maximum analysis height errors from Table 2 of Dey and Morone, and $E_T(\tilde{U}_k)$, the tropical wind EPE from Table 4 of Dey and Morone. In all three cases the interpolation procedure is identical to that used in (3). Next, force E_{a0} to be in the interval $(E_{\Delta T}, E_\infty)$. Then set $E_p(\tilde{Z}_k) = E_{a0}(\tilde{Z}_k) + E_{\Delta T}(\tilde{Z}_k)$, and calculate $E_p(\tilde{U}_k) = E_p(\tilde{V}_k)$ using equations (2.12) and (B.11) of Dey and Morone (1985) as necessary

$$E_p(\tilde{U}_k) = E_p(\tilde{V}_k) = (g/|f|)(2k_h)^{1/2}\, E_p(\tilde{Z}_k)$$

$$E_B(\tilde{U}_k) = E_B(\tilde{V}_k) = \frac{|\phi_g|}{25}\sin\left(\frac{90}{25}|\phi_g|\right) E_p(\tilde{U}_k) + \left(1 - \frac{|\phi_g|}{25}\right) E_T(\tilde{U}_k)$$

where k_h is set as in FLAGS(7). The blended values E_B are used only if $|\phi_g| < 25$. (Note that typographical errors in (B.11) have been corrected here.)

(5) Initialize variables, setting all corrections (z_{kg}, u_{kg}, v_{kg}) to zero and all estimated analysis errors (EAE) to the EPE, e.g., $E_a(z_{kg}) = E_p(\tilde{Z}_k)$.

(6) Loop over observations previously selected in ASAP1 (24), i.e., consider observations in the list NAKEY(i), i=1,NGBOX. Extract data (p_k, u_k, v_k, $Q(u_k, v_k)$, $\hat{p_k}$, $\hat{z_k}$ and $q(\hat{Z_k})$) from /RESID/ for each of these observations for each k for which data is present and store in local arrays. Observations with no data present are skipped. Since layers/levels with no data are skipped, the pressures associated with the data are stored. That is, $u_{\ell n}$ is the u residual at the <u>ℓth</u> layer which had wind <u>or</u> height data present in the <u>nth</u> observation, and the pressure of $u_{\ell n}$ is $p_{\ell n}$. the number of layer/levels extracted is stored in L_n. Local arrays of <u>dsi</u>$_n$, ϕ_n, λ_n are also formed. If $|\phi_g| > 70$, (u,v) are converted to polar stereographic corrdinates. If N, the number of observations extracted, is zero, go to (49).

(7) Assign the EPE for the residuals, $E_p(\hat{z}_{\ell n})$, $E_p(u_{\ell n})$ and $E_p(v_{\ell n})$ by finding the grid point sigma layer pressure $\tilde{P}_{k_m}$ closest to $\hat{p}_{\ell n}$ for z or $p_{\ell n}$ for (u,v) and assigning the corresponding grid point EPE to the observation EPE, e.g., $E_p(u_{\ell n}) = E_p(\tilde{U}_{k_m})$.

(8) Initialize IWFLG. Begin main loop (8-46) over layers, k=1,K+1. Layer K+1 is the underground layer. Select k_h as in FLAGS(7). $\tilde{P}_g$ is the pressure at the grid point (i.e., $\tilde{P}_k$, or $\tilde{P}_u$ if k=K+1).

(c) = (9)-(14) Selects the data to be used at this layer.

(9) Loop over all observations n = 1,N. Set $L = L_n$.

(10) Calculate d_{ng}, the distance from the observation to the grid point. For $|\phi_g| > 70°$, the polar stereographic projection is used. Calculate G_n, the coefficient of geostrophy at the observation, and μ_g^{zz}, the zz horizontal correlation. (See Section 5.6 and Dey and Morone (1985, Eq. 2.8).)

(11) Begin loop over all layer/levels in the observation $\ell = 1,L$. If a z residual is present, then add n and ℓ to list of potential z observation and levels (variables NZT(m), LZT(m), m=1,NTOTZ). Calculate the vertical correlation between $p_{\hat{\ell}n}$ and $\tilde{P}_g$ using Eq. (2.9) of Dey and Morone (1985). Obtain the estimated observation error (EOE) for this residual, $E_o(z_{\hat{\ell}n})$ (ESOBER). Define ε_m as $E_o(z_{\hat{\ell}n})/E_p(z_{\hat{\ell}n})$. Calculate ρ'^{zz}_{mg}, ρ'^{zu}_{mg} and ρ'^{zv}_{mg}, the adjusted total correlations between the height residual and the grid point variables. (Note that m implies a particular ℓ and n, while g implies k.) These adjusted correlations are the correlations obtained following Dey and Morone (1985, Eqs. (2.7), (A2), (A3), (B2), (B3) as appropriate), divided by $(1 + \varepsilon_m^2)$. These adjusted correlations are the normalized weights one would obtain for updates made using each residual separately. The sum of the absolute values of these weights is

$$\rho_m^{(1)} = |\rho'^{zz}_{mg}| + |\rho'^{zu}_{mg}| + |\rho'^{zv}_{mg}|$$

For the underground layer (i.e., if k=K+1), $\rho^{(1)} = |\rho'^{zz}_{mg}|$.

(12) Repeat (11) for wind data. If wind data are present, then:
Add n and ℓ to list of potential (u,v) observations and layers (variables NW(m), LW(m), m=1,NTOTW). Calculate vertical correlation between $p_{\ell n}$ and $\tilde{P}_g$. Obtain $E_o(u_{\ell n})$ and define ε_m as $E_o(u_{\ell n})/E_p(u_{\ell n})$. (Note that $E_p(u_{\ell n})$ is used for v as well.) Calculate ρ'^{uz}_{mg}, ρ'^{vz}_{mg}, ρ'^{uu}_{mg}, ρ'^{uv}_{mg}, ρ'^{vu}_{mg} and ρ'^{vv}_{mg}, the adjusted correlations, as in (11), but here using Eqs (A4)-(A9) or (B4)-(B9) of Dey and Morone (1985). Set

$$\rho_m^{(2)} = [\,|\rho'^{uz}_{mg}| + |\rho'^{vz}_{mg}| + |\rho'^{uu}_{mg}| + |\rho'^{uv}_{mg}| + |\rho'^{vu}_{mg}| + |\rho'^{vv}_{mg}|\,]/2$$

For the underground layer, set $\rho_m^{(2)} = [\,|\rho'^{uz}_{mg}| + |\rho'^{vz}_{mg}|\,]/2$.
End of loop (9).

(13) Determine the NLRHS (currently 10) largest $|\rho|$ greater than 0.1 from the combined set of $\rho_m^{(1)}$ and $\rho_m^{(2)}$. At this point, a (u,v) wind is considered a single piece of data. Pointers to the selected residuals are saved in $\overline{m}(i)$, $\overline{D}_T(zi)$, $i=1,\overline{I}$ (variables NNRHS(i), NVRHS(i), i=1,NKT). The insert sort algorithm (see ASAP1(24)) puts these pointers in the list in descending $|\rho|$ order.

(14) If $\overline{I}=0$ and $k < K$, go to (45). Else if $\overline{I}=0$ and $k=K+1$, go to (46).
Else $\overline{I}>0$; continue with:

(d) = (15) - (20) Calculate the observation-gridpoint prediction error correlations for the selected residuals. At this point, the u and v wind components begin to be treated separately.

(15) Set j=0. Loop over selected data i=1,$\bar{I}$. Extract $\bar{D}_T(i)$ and n(i) and $\ell(i)$ from $\bar{m}(i)$

(16) Repeat (10), calculating d_{ng}, G_n and μ_{mg}^{zz}.

(17) If $\bar{D}_T(i)$ = 1, then the current residual is a height residual: Increment j. Add it to the list of pointers, by setting m(j) = $\bar{m}(i)$ and $D_T(j)$ = 1 (variables NNRHSV, NVRHSV). Repeat (11) but store $\rho_{ng}^{\prime zz}$, $\rho_{ng}^{\prime zu}$, and $\rho_{ng}^{\prime zv}$ as the three r.h.s. of the normal equations (variable (RHSV).

(18) If $\bar{D}_T(i)$=2, then the current residual is a wind residual: Add the u component to the list of pointers as in (17). Calculate $\rho_{mg}^{\prime uz}$, $\rho_{mg}^{\prime uu}$, and $\rho_{mg}^{\prime uv}$ as in (12). Store these adjusted correlations as the three r.h.s. of the normal equations.

(19) If $\bar{D}_T(i)$=2, repeat (18) for the v component. Note: $D_T(j)$ = 3. This is the point where a wind residual is treated as two pieces of data. Calculate $\rho_{mg}^{\prime vz}$, $\rho_{mg}^{\prime vu}$, and $\rho_{mg}^{\prime vv}$ as in (12) but store as the three r.h.s. of the normal equations.

(20) End of Loop (15). Set I=j. The r.h.s. and the pointers $D_T(i)$, m(i) are complete.

(e) = (21)-(32) Calculate the matrix of observation-observation correlations.

(21) Loop on all pieces of data i=1,I. Extract $D_T(i)$, n(i), $\ell(i)$, p(i) and $E_p(x(i))$. Obtain $E_o(x(i))$ (ESOBER) and set $\varepsilon_i = E_o(x(i))/E_p(x(i))$.

(22) Calculate variables needed for the distance calculation and the correlation calculation which depend on the <u>ith</u> piece of data. Calculate G_i, the coefficient of geostrophy.

(23) Loop on all pieces of data j=i,I. If j=i, go to (31). Otherwise, obtain $D_T(j)$, n(j), $\ell(j)$, p(j), $E_p(x(j))$, $E_o(x(j))$ and ε_j as in (21).

(24) Calculate the distance d_{ij}, the coefficient of geostrophy G_j, and other variables needed for the correlation calculation.

(25) Calculate variables for the vertical correlation calculation. Calculate the horizontal correlation μ_{ij}^{zz}.

(26) Set horizontal observation error correlation (Norquist, 1986b, pp. 14-16) as

$$\mu^{zz}_{0ij} = \begin{cases} 1 & \text{if same variable and same observation } (D_T(j) = D_T(i) \text{ and } n(j) = n(i)) \text{ for } \underline{\text{type}} \text{ 1 or 2} \\ \exp(-k_{h0}d^2) & \text{for satellite heights} \\ 0 & \text{otherwise} \end{cases}$$

(27) Calculate vertical error correlations. Let $x = \ln^2(p(i)/p(j))$

Define

$$\nu_{0ij} = \begin{cases} (1 + k_{p0}x)^{-1} & \text{for heights, } \underline{\text{type}} \text{ 1 or 2} \\ (1 + k^{w}_{p0}x)^{-1} & \text{for winds, } \underline{\text{type}} \text{ 1 or 2} \\ \text{Interpolate linearly in } x \text{ in look-up table} & \text{for satellite heights (Norquist, 1986b, Table 3)} \\ 0 & \text{otherwise} \end{cases}$$

and

$$\nu_{ij} = (1 + k_p x)^{-1}$$

(28) For $|\phi_g| > 70$, calculate ρ and η using formulas from appendix A of Dey and Morone (1985). Each of the 9 cases zz, zu, zv, uz, uu, uv, vz, vu, vv are handled separately here. The statistical model for ρ is also used for η, only the constants k_h and k_p are replace by k_{h0}, k_{p0} and k^{w}_{p0}.

(29) For $|\phi_g| < 70$, calculate ρ and η using formulas from appendix B of Dey and Morone (1985).

(30) Set matrix entries $R_{ij} = R_{ji} = \rho_{ij} + \varepsilon_i\varepsilon_j\eta_{ij}$. Go to (32)

(31) Set matrix entry $R_{ii} = 1 + \varepsilon_i^2$

(32) End of loop (23) on j. End of loop (21) on i.

(f) = (33) - (39) Solve the normal equations

(33) Begin loop on data type $D_T(g) = 1,3$. For underground layer k = K+1, skip cases for $D_T(g) = 2,3$, since only the z analysis is needed.

(34) Move ρ'^{xy}_{ng} which was stored in (17)-(19) in variable RHSV to the vector of rhs b (variable RHS).

(35) If only one piece of data is present, solve for this special case $a'_1 = b_1/R_{11}$. Go to (38).

(36) Solve normal equations $Ra' = b$ using Cholesky algorithm (CHLSKY).

(37) If algorithm fails, then: Eliminate one residual which is highly correlated with another residual (RECALC). If only one residual is left, solve for this special case as in (35); otherwise, apply Cholesky algorithm again (CHLSKY). If Cholesky algorithm fails, go to (37).

(38) Calculate normalized squared analysis error A_E from Bergman's (1979) Eq. 2.11. If any of the $a'_i > 1.1$ (and if I>1), go to (37), since this is considered a failure.

(39) If the normalized squared analysis error A_E is less than zero or greater than one, skip the analysis for this variable by setting the correction C=0, A_E=0 and I=0 and going to (42a).

(40) Convert a'_i to a_i the dimensionalized weights using (Norquist, 1986b, Eq. 11)

$$a_i = a'_i \, E_g/E_p(x(i))$$

where E_g = EPE(k,$D_T(g)$) for k < K and $E_g = E_p(\tilde{Z}_1)$ for the underground layer. If $|\phi_g| < 10$, then z observations are not allowed to affect wind analyses; set a_i=0 in this case. If $|\phi_i| < 10$, then wind observations are not allowed to affect height analyses; set a_i=0 in this case. The reasoning is that if $|\phi_g| < 10$, then $G_g = 0$ and $\mu_{zu} = \mu_{zv} = 0$, while if $|\phi_i| < 10$, then $G_i = 0$ and $\mu_{uz} = \mu_{vz} = 0$. (See Dey and Morone, 1985, Eqs. (B2)-(B5)).

(41) Recalculate A_E as in (38), but skip data with a_i=0. If $A_E < 0$ (or $A_E > 1$), print a message and set A_E to 0 (or 1).

(42) Calculate C, the correction. $C = \sum_i a_i x(i)$

(43) Perform gross error check of C against ZER (250 m) or WER (25 m/s) (Norquist, 1986b, p. 17). If C passes the check, go to (44).

(43A) Set C=0, A_E=1. If C is a wind, set the flag (IWFLG(K)) so that both u and v corrections are set to zero in (48).

(44) If k=K+1, set Z_{ug}=C; otherwise, set $E_a(z_{kg})$, $E_a(u_{kg})$ or $E_a(v_{kg})$ equal to $A_E^{1/2}$ times $E_p(\tilde{Z}_k)$, $E_p(\tilde{u}_k)$ or $E_p(\tilde{v}_k)$ and z_{kg}, u_{kg} or v_{kg} equal to C if $D_T(g)$ = 1, 2 or 3. (See Eq. 2.11 of Bergman, 1979.) End of loop (33) on $D_T(g)$. Go to (46)

(45) Set $z_{kg} = u_{kg} = v_{kg} = 0$ and associated EAE to the corresponding EPE. (Like(5) but for single k only.)

(46) End of main loop (8) on layers

(47) Convert z_{kg} to t_{kg} (LOWTMP) and update first guess $\tilde{T}_k = \tilde{T}_k + t_{kg}$.

(48) Update $(\tilde{U}_k, \tilde{V}_k)$ by adding (u_{kg}, v_{kg}); first converting analysis winds back to (λ, ϕ) coordinates if $|\phi_g| > 70$.

(49) Output $\tilde{T}_k$, $\tilde{U}_k$, $\tilde{V}_k$ to unit 6 and $E_a(z_{kg})$, $E_a(u_{kg})$, $E_a(v_{kg})$ along with z_{kg}, u_{kg} and v_{kg} to unit 11. Note that only $E_a(z_{kg})$ will be used for the next analysis (see (4)). Return.

Name:	BILINR (subroutine)	
Purpose:	Interpolates a single field bilinearly.	
Author:	D. Norquist, SASC, 1980 - 1986	
Documentation:	R. Hoffman, AER, 1986	
Referenced by:	FG	
References:	none	
Commons used:	none	
Arguments:	A	f_{ij}, field array
	(X,Y)	(x,y) location in grid units
	NX	first A array dimension
	NY	(not used)
	ANS	f(x,y), interpolated value
I/O units:	none	

Description:

Determine the coordinates (i,j) of the grid point in the lower left hand corner of the grid cell enclosing the point (x,y). Determine $x' = x-i$, $y' = y-j$, the (x,y) location with respect to (i,j). Then set:

$$f(x,y) = x'y'\, f_{i+1,j+1} + x'(1-y')\, f_{i+1,j} + (1-x')\, y' f_{i,j+1} + (1-x')\,(1-y')\, f_{ij}$$

Name: CALCRES (subroutine)

Purpose: Calculate residuals for single level data.

Author: D. Norquist, SASC, 1980 - 1986

Documentation: R. Hoffman, AER, 1986

Referenced by: MASTOR2, MASTOR6

References: None

Commons used: DCONST, DEL, FGDATA, UASIGMA

Arguments:

	PO	$\tilde{P}_k$
	POH	$\tilde{P}_{\hat{k}}$
	KV	k_v

I/O units: none

Description:

(0) Residuals are returned in /DEL/.

(1) Set t, z residuals to missing.

(2) Calculate (u,v) residuals. If (U_{k_v}, V_{k_v}) is missing set (u,v) residuals to missing.

Name: CHLSKY (subroutine)

Purpose: Performs Cholesky decomposition and back substitution to solve the matrix equation Ax=b (Dahlquist and Bjorck, 1974, pp. 157-159; Stobie, 1984).

Author: D. Norquist, SASC, 1980 - 1986

Documentation: R. Hoffman, AER, 1986

Referenced by: ASAP2

References: none

Commons used: none

Arguments:

FA	matrix A
FB	r.h.s. b
N	size of system
X	solution vector
IFAIL	= 0 for normal return = 1 if a pivot smaller than 1E-7 is found.

I/O units: none

Description:

(1) Decomposition phase: Find L such that $A = LL^T$.

(2) First back substitution: Find y where Ly = b.

(3) Check for pivot too small. Note that check is independent of data b.

(4) Second back substitution: Find x where $L^T x = y$.

Name:	CNTOBS (subroutine)
Purpose	Counts and prints out the number of valid residuals classified by level and by type.
Author:	D. Norquist, SASC, 1980 - 1986
Documentation:	R. Hoffman, AER, 1986
Referenced by:	ASAP1
References:	none
Commons used:	DCONST, RESID

Arguments:

NUM	N	total number of observations
INUM		index of last observation of types 1, 4, 2, 6
ICHK	= 0	before consistency checks
	= 1	after consistency checks

I/O units: OUTPUT

Description:

(1) Initialize: write heading, zero counters.
(2) Loop over all observations, switching type index (IT) as necessary.
(3) At each level, increment height counter if $\hat{z}_k$ is present.
(4) At each level, increment wind counter if (u_k, v_k) is present. End of loop (2).
(5) Print results. Return.

Name: CQCV (subroutine)

Purpose: Translates quality indicators from GWE level II data sets to "generic quality marks". (See Section 5.2.)

Author: D. Norquist, SASC, 1980 - 1986

Documentation: R. Hoffman, AER, 1986

Referenced by: MASTOR1, MASTOR2

References: none

Commons used: none

Arguments:

IQZ		z, quality mark/indicator
IQT		T, quality mark/indicator
IQQ		q, quality mark/indicator
IQW		(u,v), quality mark/indicator
IDSI	-	(not used)
ALAT	-	(not used)
ALON	-	(not used)
P	-	(not used)

I/O units: none

Description:

(0) On input IQZ contains the GWE quality indicator, on output it contains the ASAP quality mark. The same holds for IQT, IQQ and IQW. Variable IQC contains the translation table from quality indicator to quality mark. It is based on WMO (1978), Appendix A, Table IV, Codes IH, IV and IL. IQC is therefore valid for <u>dsi</u> = 11, 12, 21-24 only.

(1) Perform translation for z. First separate two digits of input code into a horizontal and a vertical quality control indicator. Translate each separately and set the quality mark equal to their maximum. Note that a value of 99 indicates missing both for a quality mark and a quality indicator.

(2) Perform translation for T.

(3) Perform translation for q.

(4) Perform translation for (u,v).

(5) Return.

Name: ESOBER (subroutine)

Purpose: Returns estimated observation error for a given variable for a given dsi at a given pressure in a given month. Values for satellite heights are from Norquist (1986b, pp. 36-37); all other values are from Dey and Morone (1985, Table 5).

Author: D. Norquist, SASC, 1980 - 1986

Documentation: R. Hoffman, AER, 1986

Referenced by: ASAP2

References: none

Commons used: none

Arguments:

IDSI	dsi
P	P, pressure of the observation
NV	variable index; 1=Z, 2=u, 3=v
PM	P_ℓ , pressure at the mandatory levels
MANDLVL	L, the number of mandatory levels
EOV	E_o, estimated observation error
IMON	month of the analysis

Description:

(1) If (4 < IMON < 9) move June values to fourth column of EOE table, otherwise leave February values. For type 2 data (AIREPS): for dsi = 21,22, set E_o = 4.9 m/s; for dsi = 23,24, set E_o = 6.0 m/s.

(2) For type 6a data, dsi = 61 (SATWINDS): if p > 400 mb, set E_o = 4.2 m/s; if p < 400 mb, set E_o = 7.5 m/s.

(3) For type 1 data, dsi = 13,14,15 (TWOS, dropwindsondes), set E_o = 2.0 m/s. For dsi = 16 (constant level balloon), set E_o = 5.0 m/s.

(4) For all others, interpolate linearly in $\ln p$ in EOE table which has four categories (columns) for each mandatory level (rows). If $p < 50$ mb, the 50 mb value is used. If $p > 1000$ mb, the 1000 mb value is used. The four categories are

Column	Usage	dsi	NV
1	RAOB heights	11	1
2	RAOB winds	11	2,3
3	PIBAL winds	12	2,3
4	SAT heights	41	1

Name: FG (subroutine)

Purpose: Bilinearly interpolates first quess fields to the observation location. Returns results in /FGDATA/and in arguments ZSTAR, PO, POH.

Author: D. Norquist, SASC, 1980 - 1986

Documentation: R. Hoffman, AER, 1986

Referenced by: MASTOR1, MASTOR2, MASTRO4, MASTOR6

References: BILINR

Commons used: CCONST, DCONST, FGDATA, FGFLDS, SIGK

Arguments:

RLAT	ϕ
RLON	λ
ZSTAR	Z_*
PO	$\tilde{P}_k$
POH	$\tilde{P}_{\hat{k}}$
IDSI	$\underline{dsi}$
IWAT	flag for $\tilde{R}$ computation (see (3)).
NRDLAT	number of latitudes which have been read.

(Index of latitude currently stored as second latitude in /FGFLDS/. That is, $\phi_2 = -90 + (\text{NRDLAT} - 1)\ \Delta\phi$.)

I/O units: 1, 5

Description:

(0) Note that $\tilde{P}^{\cdot} = \tilde{P}_*$

(1) Determine fine grid coordinates (x,y).

(2) If y > NRDLAT, values for a new latitude are needed. Shift northern latitude values to southern latitude values in /FGFLDS/. Read in a new northern latitude, incrementing NRDLAT. Go to (2).

(3) Interpolate $\tilde{T}$, $\tilde{U}$, $\tilde{V}$, $\tilde{R}$ from /FGFLDS/ to /FGDATA/. Relative humidity is interpolated only if data is <u>type</u> 1 (RAOBS) or if data is <u>type</u> 4 (SATEMS) and IWAT $\neq$ 0.

(4) Interpolate $\tilde{P}_*$ from /FGFLDS/. Set $\tilde{P}_k$ and $\tilde{P}_k^*$ from $\tilde{P}_*$ and /SIGK/.

(5) If not <u>type</u> 6 (i.e. for RAOBS, AIREPS or SATEMS) interpolate Z_* from /FGFLDS/ and obtain heights by integrating $\tilde{T}_k$ hydrostatically.

Name: FLAGS (subroutine)

Purpose: Perform gross and buddy checks on the data stored in /RESID/ (see Norquist, 1986b, pp. 5-8). All comparisons are made within boxes approximately 10° square (see Section 5.3). Gross error check limit is ±3 forecast error standard deviations. Buddy check follows Bergman's (1978, 1979) procedure in spirit, with the addition of keep flags. Data which fail the checks are set to missing.

Author: D. Norquist, SASC, 1980 - 1986

Documentation: R. Hoffman, AER, 1986

Referenced by: ASAP1

References: none

Commons used: AS1AS2, CCONST, DCONST, IFLG, RESID, SIGK

Arguments:

IBOX	list of B_n
JDSI	list of $\underline{dsi}_n$
QLAT	list of ϕ_n
QLON	list of λ_n
PTS	- not used
NWO	- not used
NUM	N

I/O units: output

Description:

(0) The arrays used to store the data flags and indices are confusing. In the buddy check, within a box at a single layer or level, observations of the same type are compared by pairs i, j, with i < j. I will use the notation in this documentation that F_j^i means "i puts a <u>flag on</u> j", since

i is on top of j in the symbol. Also I use ${}^{w}F$ for wind flags and ${}^{z}F$ for height flags. If the data i and j are consistent, then $F_j^i = F_i^j = 0$. If they are inconsistent and i is of better quality, then $F_j^i = 1$ and $F_i^j = 0$; if they are of equal quality then $F_j^i = F_i^j = 1$ and if j is of better quality then $F_i^j = 1$ and $F_j^i = 0$.

In the code the following symbols are used

N = i	IN = i	IFWI(IN,INO) = ${}^{w}F_i^j$	IFZTI (IN,INO) = ${}^{z}F_i^j$
NO = j	INO = $j-i$	IFWJ(IN,INO) = ${}^{w}F_j^i$	IFZTJ (IN,INO) = ${}^{z}F_j^i$

(1) Prediction error standard deviations $E_p(\tilde{Z}_\ell)$, $E_p(\tilde{T}_\ell)$, $E_p(\tilde{U}_\ell)$ and $E_p(\tilde{V}_\ell)$ for the mandatory levels in 5 latitude belts are defined from Table 1 of Norquist (1986b). The constants a and b for the buddy check (cf. Eq. 7.1 of Bergman (1979)) are set to 3.0 and 1.5, one half of Bergman's values.

(2) Begin loop over the 18 10° latitude bands.

(3) Begin loop over the boxes in this band.

(4) Calculate the box index for the current box and begin loop over all observations in the box.

(5) If array overflow occurs (current dimensional constraint is 100 observations) output message and go to (6). Otherwise, add current observation to the list of observations in this box. NKB(i) = n(i), i=1, N_B is the pointer to the location in /RESID/ of the ith observation in the current box. End of loop (4).

(6) Loop over all observations in the box i=1, N_B, extracting residuals and quality marks from /RESID/ and storing them in local arrays. If $|\phi_B| >$ 70°, winds are converted to polar stereographic winds.

(7) Loop over layers selecting the appropriate k_h for this layer. (See Dey and Morone, 1985, p. 308). If $\sigma_k > 0.125$ $k_h = 2E\text{-}12m^{-2}$, if $0.125 > \sigma_k > 0.070$, then $k_h = 1.5E\text{-}12m^{-2}$, and if $0.070 > \sigma_k$, then $k_h = 1.0\ E\text{-}12m^{-2}$.

(8) Initialize all toss flags and keep counters to zero.

(9) Begin loop over all observations in the current box. Determine indices of the mandatory levels above and below the layer and level pressures of the current data. That is find ℓ_b, ℓ_a, $\ell_{\hat{b}}$, $\ell_{\hat{a}}$ such that

$$\bar{P}^{*}_{\ell_b} > \tilde{P}_{*}\,\sigma_k > \bar{P}^{*}_{\ell_a}$$

$$\bar{P}^{*}_{\ell_{\hat{b}}} > \tilde{P}_{*}\,\sigma_{\hat{k}+1} > \bar{P}^{*}_{\ell_{\hat{a}}}$$

Also determine the latitude belt for looking up the forecast error standard deviations.

(10) Interpolate $E_p(\tilde{Z}_{\hat{\ell}})$ to $\sigma_{\hat{k}+1}$ and $E_p(\tilde{U}_\ell)$, $E_p(\tilde{V}_\ell)$ to σ_k linear in ℓn p. Below 1000 mb extrapolation is used, above 50 mb the value at 50 mb is used.

(11) Perform gross error check on current observation at current layer/level. Residuals greater than 3 forecast standard deviations are rejected, by changing their values and associated quality marks to missing. A list of observations in the current box which have failed one or more checks (gross or buddy) is maintained: NCH(m) for m=1, ICH is the mth observation which has failed a check. (See (33) and (38).) Note that at statement label 72 NCHT is 1 if a height error has been detected and 2 if a wind error has been detected. End of loop (9) on observations.

(12) If there is more than one observation start a loop over all observations i=1, N_B. This loop sets the initial flags. Set n(i) = NKB(i); this is the location of the ith observation in /RESID/.

(13) Determine the coordinates of the ith observation for distance calculation. A polar stereographic projection is used if $|\phi_B| > 70$.

(14) Begin loop over j= i+1, N_B. Set n(j) = NKB(j); this is the location of jth observation in /RESID/.

(15) Calculate coordinates of jth observation as in (13) and d_{ij}, the distance between the two observations as in ASAP1 (21-22).

(16) Calculate the horizontal zz correlation (Dey and Morone, 1985, Eq. 2.8) and the vertical correlation (ibid., Eq. 2.9) using layer pressures. If z_i or z_j is missing go to (19). Otherwise calculate the vertical correlation (Eq. 2.9) using level pressures, and the value of ρ^{zz} of the zz total correlation (ibid., Eq. 27). Calculate the r.h.s. and ℓ.h.s. of the buddy check criterion for z (Bergman, 1979, Eq. 7.1): these are $(a-b\rho_{ij}^{xx})E_p(x)$ and $|x_i-x_j|$.

(17) Determine $Q_L(z_i)$ and $Q_L(z_j)$, the z quality levels. (See Section 5.2.)

(18) If the buddy check criterion is violated for z, then set toss flags:

(a) If $Q_L(z_i) < Q_L(z_j)$ then ${}^zF_j^i = 1$ and

(b) If $Q_L(z_j) < Q_L(z_i)$ then ${}^zF_i^j = 1$.

If the criterion is not violated and if $|\rho_{ij}^{zz}| > 0.75$, then increment the keep counters ${}^zK_i$, ${}^zK_j$.

(19) If either wind is missing go to (22). Calculate $|\rho_{ij}^{uu}|$ and $|\rho_{ij}^{vv}|$ using equations from Dey and Morone (1985; either (A6) and (A9) or (B6) and (B9) as appropriate).

(20) Determine wind quality levels $Q_L(u_i,v_i)$, $Q_L(u_j,v_j)$. $Q_L(u_i,v_i)$, $Q_L(u_j,v_j)$.

(21) Set flags for winds as in (18). The buddy check criterion is violated if either u or v components violate their separate tests. The keep counters are incremented only if $|\rho_{ij}^{uu}|$ and $|\rho_{ij}^{vv}|$ are both > 0.75.

(22) End loop (14) on j. End loop (12) on i.

(23) Loop over all observations in the box. Remove all toss flags on observations which have 2 or more keep flags, i.e. If $({}^zK_i > 1)$ then ${}^zF_i^j = 0$ for $j = 1, N_B$ and similarly for the winds.

(24) Initialize interative rejection cycle. The minimum number of toss flags which require an observation to be tossed (N_T) is set to 2, unless there are only 2 observations in a box in which case it is set to 1.

(25) Begin rejection cycle. Initialize sums $({}^wS_i, {}^zS_i, N_K)$. Begin loop over all observations in box, $i=1,N_B$. (Arrays IQZ and IQW are used here for ${}^wS_i$ and ${}^zS_i$.)

(26) Accumulate the number of toss flags on i for $j > i$. (Process F_i^j for $j > i$).

(27) Accumulate the number of toss flags on j by i for $j > i$. (Process F_j^i for $j > i$). Note (25-27) are equivalent to creating the sums

$$S_i = \sum_{j=1}^{N_B} F_i^j \quad \text{for all } i \text{ and for } z \text{ and } (u,v).$$

(28) If ${}^wS_i < N_T$ and ${}^zS_i < N_T$ then increment N_K the number of observations which are assured of being kept. End loop (25) on i.

(29) If $N_K = N_B$ then all observations remaining are acceptable: go to (35). Otherwise there are more to be tossed.

(30) Determine minimum and maximum number of toss flags (min S_i, max S_i) and the index i_{max} which corresponds to the observation with the maximum, for both z and (u,v), separately.

(31) If max S_i is > 4 truncate to a multiple of 4 (e.g. 7 becomes 4) for both z and (u,v), separately.

(32) Toss data (by setting the local residuals to missing) for those i which have S_i > the (truncated) max S_i. Maintain a list of pointers to the observations in the local arrays which have been tossed during this rejection cycle., e.g. NZ(m), m=1, INTZ contains the pointers to the tossed z observations.

(33) Update the list of pointers to observations which have failed one or more tests (NCH(m), m=1, ICH) to reflect changes made in (32) using the NZ and NW lists.

(34) Remove all toss flags imposed by observations which have just been tossed on other observations. That is for i=1, N_B if S_i > (truncated) max (S_i) then set $F_j^i = 0$ for j=1, N_B, for z and (u,v) separately.

(35) Go to (25) to start next iteration unless 10 iterations have already been performed.

(36) Loop on observations in the box i=1,N_B. Restore IQZ, IQW arrays from /RESID/. These arrays (Q(z),Q(u,v)) were used to store ${}^zS_i$ and ${}^wS_i$. Since some observations have been tossed, set Q(z) to missing if the z residual is missing, and set Q(u,v) to missing if the (u,v) residual is missing. Check if any observations still might be tossed. If this occurs, print message.

(37) End of loop (7) on layers.

(38) Move changes back to OBD array, using list NCH. If $|\phi_B| > 70$ convert winds from polar stereographic back to (λ, ϕ) coordinates.

(39) End of loops (2) and (3) on buddy check boxes. Print message and return.

Name: LOWTMP (subroutine)

Purpose: Converts analyzed residuals z_k to temperature residuals t_k and corrects the first guess value $\tilde{T}_k$. (See Norquist, 1986b, p. 18, pp. 55-58.)

Author: D. Norquist, SASC, 1980 - 1986

Documentation: R. Hoffman, AER, 1986

Referenced by: ASAP2

References: none

Commons used: DCONST, LOWT

Arguments:

CORZ	z_k, layer analysis
CORZU	z_u, underground layer analysis
TG	$\tilde{T}_k$, first guess on input, updated analysis on output
SL	scaled pressures p_k
SLU	scaled pressure p_u in the layer underground
Note:	all arguments are variables for the grid point being analyzed.

I/O units: none

Description:

(0) Vertical indexing used in this subroutine is illustrated in the following figure. The first value is used in (1) and (4). The second value is used otherwise.

$k = K+1, K$	top of the atmosphere
$k = K, K-1$	
.	
.	
.	
$k = 3,2$	
$k = 2,1$	
$k = 1$	surface

(1) Compute T corrections between two layers (i.e., at "interfaces"),

$$t^{\wedge}_k = (z_k - z_{k-1})/(\ln p_k - \ln p_{k-1}) \quad k = 2,\ldots,N_k+1$$

These temperatures must be multiplied by $-g/R$ to become dimensionalized (see (3)).

(2) Reset index so that $t^{\wedge}_k = t^{\wedge}_{k+1} \quad k = 1,\ldots,N_k$

(3) Apply Flattery algorithm, treating $t^{\wedge}_k$ as layer temperatures. Since the sigma structure /SIGK/ doesn't change, the required constants are stored in /LOWT/. First form $BT^{\wedge}$, then $A^TBT^{\wedge}$ and finally $(A^TA)^{-1}A^TBT^{\wedge}$. Here $T^{\wedge}$ is the vector of $t^{\wedge}_k$. Dimensionalize the result by $-g/R$ to get T, the layer temperatures.

(4) Set uppermost layer residual to zero: $t_{K+1} = 0$. (Note: layers include subsurface layer.) Update temperatures $\tilde{T}_k = \tilde{T}_k + t_{k+1} \quad k = 1,K$.

Name: LOWTMPS (subroutine)

Purpose: Implements the Flattery algorithm for interpolating layer temperatures to level temperatures by the method of least squares. This version assumes the topmost pressure is greater than zero. There should be no missing values. (See Norquist, 1986b, Appendix A, pp. 55-58.)

Author: D. Norquist, SASC, 1980 - 1986

Documentation: R. Hoffman, AER, 1986

Referenced by: SATLTMP

References: MATRIX

Commons used: DCONST

Arguments:

TLAY	T_ℓ	
ML	$L - 1$	
TL	$\hat{T}_\ell$, level temperature	
PL	$\hat{P}_\ell$ (in practice these are scaled.)	
ATA	$(A^TA)^{-1}$	
MLPI	L	

I/O Units: none

Description:

(0) Note that the maximum number of levels is 20.

(1) Set scale for temperatures to $-g/R$. Calculate weights for interpolating layer to level temperatures for levels 2,...,L-1. Note that the sum of the two weights is one. Layer pressures are assumed to be given by $P_\ell = (\hat{P}_\ell \hat{P}_{\ell+1})^{1/2}$.

(2) Form A^T matrix.

(3) Form $(A^TA)^{-1}$ matrix.

(4) Form BT, first scaling the temperatures. Note special handling of BT(L) and BT(2L-1) corresponding to levels 1 and L.

(5) Form A^T(BT).

(6) Calculate level temperatures $(A^TA)^{-1}$ $(A^T BT)$ and dimensionalize.

Name: MASTOR1 (subroutine)

Purpose: Reads type 1 data (RAOBS) from unpacked GWE Level II data set, interpolates to sigma and calculates residuals, which are then stored in /RESID/. (See Norquist, 1986b, pp. 31-33.)

Author: D. Norquist, SASC, 1980 - 1986

Documentation: R. Hoffman, AER, 1986

Referenced by: ASAP1

References: CQCV, FG, PTOSIG

Commons used: DCONST, FGDATA, RESID, UADATA, UASIGMA

Arguments:

IDATE	date	
ITIME	time	
NW	-	(not used)
NUM	N	
QLAT	list of ϕ_n	
QLON	list of λ_n	
JDSI	list of $\underline{dsi}_n$	
IBOX	list of B_n	

I/O Units: 2,OUTPUT

Description:

(1) Initialize time and date window as ± 3 hours about date/time which was input. Set ICHNG = 0; this is a flag used to overwrite a previous observation with a new observation of higher quality. Initialize N, L.

(2) Read a record from unit 2, using format described by Norquist, (1984, pp. 18-19). On EOF go to (19).

(3) If not acceptable go to (2). Specifically dsi = 75, cloud data, are skipped. The presence of other non-type 1 data results in an ABEND. Records with missing p, negative z or date/time not in the window are skipped.

(4) If λ, ϕ or dsi do not match λ_N, ϕ_N, or dsi_N, go to (12). That is if current record is not part of current observation, it is time to complete processing the current observation and begin new one. Note that the test makes use of fact that λ, ϕ are coded only to hundreths of degree.

(5) If level dimension (currently 90) is exceeded in /UADATA/, skip this level, go to (2).

(6) If this is not the first level for the current observation, i.e., if $\ell \neq 1$, go to (8). Set λ_N, ϕ_N, dsi_N to λ, ϕ, dsi. Calculate B_n (see Section 5.3).

(7) If N > 1, then loop over all previous observations searching for a matching λ_n, ϕ_n. If match is found then: If dsi < dsi_n, then the new observation is better (see WMO (1978), Appendix A, Table 1). Set ICHNG = 1 to force overwriting observation n. (To do this temporarily set N = n.) Go to (8). Else if dsi > dsi_n, then flush current records until new location is found. Go to (3).

(8) Translate T in Celsius to T in Kelvin, T_d to Q, wind speed and direction to (U,V). If quality indicator is 99 for any variable, set corresponding value to missing (DNN = -999.9). Winds at the pole are set to missing.

(9) Combine quality indicators and translate into qualtiy marks (CQCV).

(10) Set all quality marks > 1 to 99, set corresponding values to missing. This keeps only data which have been checked satisfactorily and data which have not been checked.

(11) Increment L. Go to (2).

(12) Save λ, ϕ for the new observation which has been detected. If L = 1 (which can happen only if N = 1), go to (6).

(12a) Eliminate duplicate and/or out of order levels from current observation.

(13) Calculate first guess values at λ_N, ϕ_N for Z_*, $\tilde{P}_k$, $\tilde{T}_k$, $\tilde{U}_k$, $\tilde{V}_k$ and $\tilde{Z}_k^{\wedge}$ (FG). Although IWAT = 0, $\tilde{R}_k$ is calculated, since this is type 1 data.

(14) If the observation has only a single level skip it by going to (17a). Interpolate observation to sigma coordinates (PTOSIG). If all sigma coordinate data is missing go to (17a). Convert Q_k to R_k. If Q_k or T_k is missing, then R_k is missing.

(15) Compute residuals. Make sure that missing data results in missing residuals.

(16) Store residuals and associated quality marks in /RESID/. (At this point quality marks are either 0 for checked residuals, 1 for unchecked residuals, or 99 for missing residuals.)

(17) Restore N, ICHNG if overwriting. Increment N for next observation.

(17a) If EOF go to (19). Otherwise move contents of current record to start of /UADATA/ arrays, since this data is start of the new current observation. This resets L = 1. Go to (6).

(18) Position unit 2 at start of next file. Go to (12a)

(19) Undo (17): N = N-1. Return.

Name: MASTOR2 (subroutine)

Purpose: Reads type 2 data (AIREPS, etc.) from unpacked GWE Level II data set. From each report (u,v) residuals are calculated and assigned to the analysis layer closest to the reported height. (See Norquist, 1986b, pp. 33-34.)

Author: D. Norquist, SASC, 1980 - 1986

Documentation: R. Hoffman, AER, 1986

Referenced by: ASAP1

References: CALCRES, CQCV, FG

Commons used: DCONST, DEL, FGDATA, RESID, UADATA, UASIGMA

Arguments:

IDATE	date	
ITIME	time	
NW	-	(not used)
NUM	N	
QLAT	list of ϕ_n	
QLON	list of λ_n	
JDSI	list of $\underline{dsi}_n$	
IBOX	list of B_n	

I/O Units: 2

Description:

(1) Initialize date/time window as ± 3 hours about input date/time. Initialize N for next observation. Initialize /UASIGMA/ humidities to missing (Q_k) . Initialize all of /UADATA/ to missing (P_ℓ, T_ℓ, U_ℓ, V_ℓ, Q_ℓ, Z_ℓ). Initialize all of /FGDATA/ to missing ($\tilde{\hat{Z}}_k$, $\tilde{T}_k$, $\tilde{U}_k$, $\tilde{V}_k$, $\tilde{R}_k$) .

(2) Read a type 2 header record. See Norquist, (1984, pp. 20-21). At EOF go to (23).

(3) Check if data is acceptable. Non-type 2 data results in an ABEND. Data outside date/time window are skipped by going to (22).

(4) Set ϕ_N, λ_N, and dsi_N to values read. Calculate B_N (see Section 5.3).

(5) If current observation is collocated with any previous observation, including those of other data types, the current observation is skipped by going to (22).

(6) Store Z and T and associated quality marks from the header record, converting degrees Celsius to degrees Kelvin.

(7) Loop on wind records associated with current header record which was read in (2). (Currently sorted data always have a single wind per header record.) First wind report is preset to missing, then data are skipped if quality mark indicates wind information is missing or if location is at the pole. Otherwise wind speed and direction are converted to (U, V) and the quality mark is saved.

(8) Skip the optional record if present.

(9) Translate the quality indicators to quality marks (CQCV).

(10) Only quality marks of 0 and 1 are retained. If $Q(Z) > 1$, skip this observation by going to (2). If $Q(T) > 1$ or $Q(U,V) > 1$, the associated values and quality marks are set to missing.

(11) Interpolate first guess to λ_N, ϕ_N (FG). Note that $\tilde{R}$ is not interpolated.

(12) If $Z < Z_*$ or $Z > \tilde{Z}_{\hat{K}}$, then go to (21). Otherwise determine the index k_c of the $\tilde{Z}_{\hat{k}}$ closest to Z .

(13) Calculate the pressures associated with $\tilde{Z}_{\hat{k}_c}$ and $\hat{Z}$ using formulas for a standard atmosphere as described by Norquist (1986b, Eq. 24 and subsequent discussion). Call these $P(\tilde{Z})$ and $P(\hat{Z})$.

(14) The actual pressure associated with the observation is then taken to be p defined so that $p - P_{\hat{k}_c+1} = P(\hat{Z}) - P(\tilde{Z})$.
(Note that $\tilde{z}_{\hat{k}}$ is at pressure $p_{\hat{k}+1}$.)

(15) Determine the sigma layer k_v which has pressure closest to p.

(16) If T is present, interpolate first guess linear in $\ln$ p to p and then add residual to $\tilde{T}_{k_v}$ to obtain T_{k_v}. This effectively assigns the residual to layer k_v. If T is not present set T_{k_v} to missing.

(17) If (U,V) is present interpolate first guess linear in $\ln$ p to p and then add the residual to $(\tilde{U}_{k_v},\tilde{V}_{k_v})$ to obtain (U_{k_v},V_{k_v}). This effectively assigns the residual to layer k_v. If (U,V) is not present, set (u_{k_v},v_{k_v}) to missing.

(18) For all $k \neq k_v$, set T_k, U_k, V_k to missing.

(19) Compute residuals (CALCRES).

(20) Store results in /RESID/. Each observation contains only $\tilde{P}_*$, u_{k_v}, v_{k_v}. Increment N.

(21) If only a single wind is associated with the current header go to (2). This will always be the case with sorted data. Otherwise process other wind data roughly following steps (4), (11), (12), (13), (14), (15), (17), (19), (20). Then go to (2).

(22) Skip wind record(s) and the optional record if it is present, which are associated with current header record.

(23) On EOF position unit 2 after the EOF mark. Undo last N increment and return.

Name:	MASTOR4 (subroutine)
Purpose:	Reads in SATTEMS from GWE level II unpacked data set which does not include SATTEMS over land. Data is transformed to sigma coordinate height residuals and stored in /RESID/. (See Norquist 1986b, pp. 34-36.)
Author:	D. Norquist, SASC, 1980 - 1986
Documentation:	R. Hoffman, AER, 1986
Referenced by:	ASAP1
References:	FG, SATLTMP
Commons used:	DCONST, FGDATA, RESID, UADATA, UASIGMA

Arguments:

IDATE	date	
ITIME	time	
NW	-	(not used)
NUM	N	
QLAT	list of ϕ_n	
QLON	list of λ_n	
JDSI	list of $\underline{dsi}_n$	
IBOX	list of B_n	

I/O Units: 2

Description:

(1) Initialize date/time window as ± 3 hours about date/time as input. Increment N for next observation. Initialize observations interpolated to sigma as missing for U, V and Q, i.e., $U_k = V_k = Q_k =$ DNN. Initialize all first guess values at observation location to missing; i.e., $\tilde{\hat{Z}}_k = \tilde{U}_k = \tilde{V}_k = \tilde{R}_k = \tilde{T}_k =$ DNN.

(2) Read in type 4 data record. This should be the group header record for a number of layer records (see Norquist, 1984, pp. 25 - 27). On EOF go to (18)

(3) If not acceptable go to rejection loop. Specifically dsi must be 41 and the date/time must be acceptable. Note: soundings over land are not included in the input data set.

(4) Set λ_N, ϕ_N, dsi_N to values read. Calculate B_N.

(5) If collocated with a previous observation, possibly of another type, go to rejection loop (17).

(6) Set quality mark to 0 if IQCI (WMO (1978), Appendix A, Table 38) and ISCR (WMO (1978), Appendix A, Table 37) indicate observation was found correct during quality control. Quality mark is set to 1 if observation was not checked. All other observations are skipped by going to rejection loop (17). Note that this specifically excludes observations corrected during Special Effort activities.

(7) Begin reading layer data records. See Norquist (1984, pp. 26-27) for details on the four types of layer information. MASTOR4 assumes that thickness and mean temperatures are not both present and that standard and nonstandard layer precipitable water are not both present. Obtain first guess values for Z_*, $\tilde{P}_k$, $\tilde{P}_{\hat{k}}$, $\tilde{T}_k$, $\tilde{U}_k$, $\tilde{V}_k$, $\tilde{Z}_{\hat{k}}$, and if layer precipitable water is present, $\tilde{R}_k$.

(8) If no thickness data is present go to (12). Read data into arrays of P_ℓ and Z_ℓ where P_ℓ is the pressure at the top of layer ℓ, Z_ℓ is the height at P_ℓ relative to P_1. Thus $Z_1 = 0$. The layer temperatures T_ℓ are then calculated hydrostatically (see Section 5.1.2). Go to (10).

(9) For mean temperature data P_ℓ and T_ℓ are read in. Data associated with missing pressures or with layers of zero or negative mass (Δp) are skipped. The pressure at the lower boundary should match the previous upper boundary pressure. If it is too large an error exists, if too small, then a layer with missing T_ℓ is defined between the two

pressures. Indexing used here is normal: T_ℓ is the mean temperature between P_ℓ and $P_{\ell+1}$.

(10) Interpolate T_ℓ to T_k (at sigma layers) and Z_k^* (at sigma levels) using Flattery algorithm and hydrostatic relationship along with some first guess information (SATLTMP). Note dimensional limit of 20 layers in matrix ATA.

(11) Set quality marks for Z_k^* and T_k equal to the quality mark defined in (6) for all levels which have data and to 99 for missing data. The layer by layer quality marks of the Level II data are ignored. Go to (13).

(12) Thickness data is not present; set all quality marks and all T_k, and Z_k^* data values, to missing in /UASIGMA/.

(13) Skip records corresponding to layer precipitable water data. Set all associated quality marks and data values to missing in /UASIGMA/. If mean temperature data is to be read next, then go to (9).

(14) Begin computation of residuals. Store $\tilde{P}_*$ in /RESID/. Code is present here to convert Q to R (see Section 5.1.4). However, Q will always be missing (see (13)).

(15) Calculate residuals; if data is missing in /UASIGMA/, the quality marks and residuals are set to missing. Wind quality marks and residuals are automatically set to missing. All residuals are stored in /RESID/.

(16) Increment N and go to (2).

(17) Rejection loop: Read thru all records of the current sounding. Go to (2). Unexpected EOF results in an ABEND here.

(18) EOF handling (see (2)).

Name: MASTOR6 (subroutine)

Purpose: Reads in type 6a data (SATWINDS) from unpacked GWE Level II data set. From each report, (u,v) residuals are calculated and assigned to the sigma layer closest to the reported pressure. (See Norquist, 1986b, pp. 41-42.)

Author: D. Norquist, SASC, 1980 - 1986

Documentation: R. Hoffman, AER, 1986

Referenced by: ASAP1

References: CALCRES, FG

Commons used: DCONST, DEL, FGDATA, RESID, UADATA, UASIGMA

Arguments:

IDATE	date
ITIME	time
NW	- (not used)
NUM	N
QLAT	list of ϕ_n
QLON	list of λ_u
JDSI	list of $\underline{dsi}_n$
IBOX	list of B_n

I/O Units: 2, OUTPUT

Description:

(1) Set up quality mark translation tables ICP and ICW (see (7)). Initialize date/time window as ± 3 hours about input date/time. Increment N for next observation.

(2) Initialize /UASIGMA/ humidities to missing ($\hat{Q}_k$) . Initialize all /UADATA/ to missing (P_ℓ, T_ℓ, U_ℓ, V_ℓ, Q_ℓ, Z_ℓ) . Initialize all /FGDATA/ to missing ($\tilde{Z}_{\hat{k}}$, $\tilde{T}_k$, $\tilde{U}_k$, $\tilde{V}_k$, $\tilde{R}_k$) .

(3) Read a <u>type</u> 6a record. See Norquist (1984, pp. 29-30).

(4) Check if data is acceptable. Non-<u>type</u> 6a data results in an ABEND. Data outside date/time window are skipped by going to (3).

(5) Set ϕ_N, λ_N, $\underline{dsi}_N$ to values read. Calculate B_N (see Section 5.3).

(6) If current observation is collocated with any previous observation, including an observation of another data type, the current observation is skipped by going to (3). Note collocation criterion agreement to 0.1 degrees in latitude and longitude since for these data location is coded to 0.1 degrees, but other data are coded to 0.01 degrees.

(7) Set quality marks Q(T) and Q(U,V) from quality indicators IQCP and IQC read at (3) using the translation tables ICP and ICW. These tables translate WMO (1978) Appendix A Tables 30 and 36 into the ASAP "generic quality marks" (see Section 5.2). Note that values of IQCP or IQC > 3 are translated to a quality mark of 5. However Table 36 has been extended by the USA Special Effort (U. of Wisconsin) to include indicators ranging from 5-9. Data with IQC indicators 6 and 7 should be translated to a quality mark of 0, 5 to 1, 8 to 6 and 9 to 8.

(8) If T is missing or Q(T) > 1, set T and Q(T) to missing. Otherwise convert degrees Celsius to degrees Kelvin.

(9) If wind speed or direction is missing or Q(u,v) > 1, set (u,v) and Q(u,v) to missing. Otherwise convert wind speed and direction to (u,v).

(10) If T and (u,v) are missing skip this observation by going to (3).

(11) Interpolate first quess to λ_N, ϕ_N (FG). Note that $\tilde{R}$ is not interpolated.

(12) If reported pressure P is not between top and bottom sigma layer pressures, $(\tilde{P}_1, \tilde{P}_K)$ then skip the current observation by going to (3). Otherwise determine k_v, the index of the sigma layer pressure closest to the observation pressure.

(13) If T is present, interpolate first guess linear in ℓn p to P and then add residual to $\tilde{T}_{k_v}$ to obtain T_{k_v}. This effectively assigns the residual to k_v. If T is missing, set T_{k_v} to missing.

(14) If (u,v) is present interpolate first guess linear in ℓn p to P and then add the residual to $(\tilde{U}_{k_v}, \tilde{V}_{k_v})$ to obtain (U_{k_v}, V_{k_v}). This effectively assigns the residual to k_v. If (u,v) is missing, set (U_{k_v}, V_{k_v}) to missing.

(15) For all $k \neq k_v$, set T_k, u_k, v_k to missing.

(16) Compute residuals (CALCRES).

(17) Store results in /RESID/. Each observation contains only $\tilde{P}_*$, u_{k_v}, v_{k_v}.

(18) Increment N and go to (3) unless N now exceeds 6000, the current array dimension in /RESID/.

(19) EOF or dimensions exceeded. Close unit 2. Undo last N increment. Return.

Name: POINTS (subroutine)

Purpose: Calculates the number of data quantity points (PTS) for each observation. Data quality of SATEMS is accounted for. Additional credit is given if z and (u,v) are both present. (See Norquist, 1986b, pp. 8-9.)

Author: D. Norquist, SASC, 1980 - 1986

Documentation: R. Hoffman, AER, 1986

Referenced by: ASAP1

References: none

Commons used: DCONST, RESID

Arguments:

JDSI	$\underline{dsi}_n$
PTS	$\underline{points}_n$
NUM	N

I/O units: none

Description:

(1) Loop over all observations n=1, N. Initialize $\underline{points}_n = 0$.

(2) Set factor to 1.0 unless $\underline{dsi}_n/10=4$ (i.e. SATEMS) in which case factor is set to the ratio of the observational standard deviations of RAOBS to SATEMS (0.42 in winter and 0.53 in summer).

(3) Loop over all layers k = 1, K.
If $\hat{z}_{kn}$ is present add factor to $\underline{points}_n$.
If $(u,v)_{kn}$ is present add factor to $\underline{points}_n$.
If $\hat{z}_{kn}$ and $(u,v)_{kn}$ are present add factor to $\underline{points}_n$.

(4) End loop (3) on k. End loop (1) on n. Return.

Name: PTOSIG (subroutine)

Purpose: Interpolates RAOBS to sigma. Assumes that temperature varies linearly in ℓn p and hence that height varies quadratically in ℓn p. Both T_ℓ and Z_ℓ observations are used to calculate T_k, the sigma layer temperatures. The T_k supplemented by first guess heights as needed are used to calculate the $\hat{Z_k}$. Winds and ℓn (specific humidity) are interpolated linearly in ℓnp. (See Norquist 1986b, pp. 32-33, 61-63.)

Author: D. Norquist, SASC, 1980 - 1986

Documentation: R. Hoffman, AER, 1986

Referenced by: MASTOR1

References: none

Commons used: DCONST, FGDATA, UADATA, UASIGMA

Arguments:

NLVL	L
ZSTAR	Z_*
PO	$\tilde{P}_k$
POH	$\tilde{P}_k$

I/O units: none

Description:

(1) Begin loop over all sigma levels k=1, K+1. This loop interpolates Z_ℓ and T_ℓ to a preliminary estimate of $\hat{Z_k}$. Find ℓ_1, the first ℓ=1, L such that $P_\ell < \tilde{P}_k$. Go to (3).

(2) Fall through loop. If P_L is within 0.1 mb of $\tilde{P}_{K+1}$, allow extrapolation of z by setting ℓ_1 = L. Otherwise go to (8).

(3) If $\ell_i = 1$ go to (8). (No downward extrapolation.)

(4) If $(P_{\ell_i - 1} - P_\ell) > 300$, go to (8).

(5) Find ℓ_ℓ, the first level ℓ at or below ℓ_i-1 which has both Z_ℓ and T_ℓ data. Find ℓ_u, the first level ℓ at or above ℓ_i which has both Z_ℓ and T_ℓ data. If either can't be found, go to (8).

(6) If $(P_{\ell_\ell} - P_{\ell_u}) > 300$ mb, go to (8).

(7) Interpolate Z_ℓ and T_ℓ quadratically in ℓn p to obtain the preliminary estimate of Z_k . Note that here Z_k is the height at $\tilde{P}_k$, not at $\tilde{P}_{k+1}$. This algorithm is comprised of Eqs. C7, C3, C6, C2 and C1 of Norquist (1986b, pp. 61-62), except that the constants A and B are multipled by (-1) everywhere. The quality mark $Q(\hat{Z}_k)$ is set equal to the maximum of the quality marks associated with the four input data, T_ℓ and Z_ℓ at ℓ_ℓ and ℓ_u. Go to (9).

(8) Do not interpolate. Set Z_k to missing.

(9) End of loop (1) on levels.

(10) Compute T_k, k=1,K hydrostatically from preliminary estimates of $\hat{Z}_k$ calculated in loop (1)-(9). Set $Q(T_k)$ equal to the maximum of $Q(\hat{Z}_k)$ and $Q(\hat{Z}_{k+1})$. If either of $\hat{Z}_k$ or $\hat{Z}_{k+1}$ is missing, then T_k is missing.

(11) Calculate final $\tilde{\hat{Z}}_k$ for k=1,K hydrostatically from T_k and Z_b. Now $\hat{Z}_k$ is at $\hat{P}_{k+1}$. Z_b is an estimate of Z at the bottom of layer k. For k=1, $Z_b = Z_*$; for k>1, $Z_b = \hat{Z}_{k-1}$ if it is present or $z_b = \tilde{\hat{Z}}_{k-1}$ if $\hat{Z}_{k-1}$ is missing. If T_k is missing, then $\hat{Z}_k$ is missing. Quality marks are set so that $Q(\hat{Z}_k) = Q(T_k)$.

(12) Begin loop on layers k=1, K. This loop interpolates (u,v) and ℓn q. Find ℓ_i, the first ℓ=1, L such that $P_\ell < \tilde{P}_k$. Go to (15).

(13) Fall through loop. If P_L is within 0.1 mb of $\tilde{P}_k$, use the values and quality marks of P_L, for U_k, V_k, Q_k $Q(U_k, V_k)$ and $Q(Q_k)$. Go to (21). Otherwise,

(14) Do not interpolate. Set (U_k,V_k), Q_k to missing. Go to (21).

(15) If ℓ_i=1 go to (14). If $(P_{\ell_i-1} - P_{\ell_i}) > 300$ mb, go to (14).

(16) Find ℓ_ℓ, the first level at or below ℓ_i-1 which has (U,V) data. Find ℓ_u the first level at or above ℓ_i which has (U,V) data. If either can't be found go to (19).

(17) If $(P_{\ell_\ell} - P_{\ell_u}) > 300$ mb, go to (19).

(18) Interpolate winds at ℓ_ℓ and ℓ_u linearly in ℓn p to $\tilde{P}_k$ to obtain (U_k,V_k). Set $Q(U_k,V_k)$ to maximum of $Q(U_\ell,V_\ell)$ at ℓ_ℓ and ℓ_u. Go to (20).

(19) Do not interpolate. Set (U_k,V_k) to missing.

(20) Repeat (16)-(19) for ℓn (specific humidity). (See Mitchell, 1985.)

(21) End of loop (12) on layers. Return.

Name: RECALC (subroutine)

Purpose: Eliminates the observation i for i > j such that ρ_{ij}, the observation-observation correlation is largest.

Author: D. Norquist, SASC, 1980 - 1986

Documentation: R. Hoffman, AER, 1986

Referenced by: ASAP2

References: none

Commons used: none

Arguments:

RHO	matrix of ρ_{ij}
RHS	vector of ρ_{ig}
NNRHS	pointer to pointer arrrays
NVRHS	variable types
NEQS	order of the system
AP	work space

Description:

(1) Determine position of maximum ρ_{ij}. Only the row position i_{max} is actually needed.

(2) Copy arrays to temporaries, skipping observation i_{max}.

(3) Copy temporaries back to input variables.

Name: SATLTMP (subroutine)

Purpose: Computes sigma layer temperatures and sigma level heights from satellite observed layer temperatures, using the Flattery algorithm to anchor temperatures and first guess $\tilde{P}_*$ or $\tilde{Z}_{\hat{k}}$ to anchor heights. (See Norquist, 1986b, pp. 35-36.)

Author: D. Norquist, SASC, 1980 - 1986

Documentation: R. Hoffman, AER, 1986

Referenced by: MASTOR4

References: LOWTMPS

Commons used: DCONST, FGDATA

Arguments:		
	P	$P_{\hat{\ell}}$, level pressures
	T	T_{ℓ} , layer temperatures
	ATA	$(A^TA)^{-1}$ workspace
	NLVL	L
	ZS	$Z_{\hat{k}}$
	TSIG	T_k
	PSIG	$\tilde{P}_k$
	POH	$\tilde{P}_{\hat{k}}$
	ZSTAR	Z_*

I/O Units: none

Description:

(1) Set output $Z_{\hat{k}}$ and T_k to missing. Return if any of the input temperatures (T_{ℓ}) are missing.

(2) Calculate scaled pressures, $s_{\hat{\ell}} = p_{\hat{\ell}}/p_{\hat{1}}$.

(3) Use Flattery algorithm (LOWTMPS) to obtain level temperatures ($T_\ell^\wedge$ = TSL) from the layer temperatures (T_ℓ).

(4) Method 1 calculation (not presently in use) interpolates $T_\ell^\wedge$ to T_k. T_k is defined as missing if there are not two pressure levels surrounding it, or if one of the surrounding $T_\ell^\wedge$ values is missing. (There should be no missing values see (1).) Interpolation in linear in ℓn p. $Z_k^\wedge$ is then calculated hydrostatically.

(5) Method 2, which used 400 mb as the prime anchor level, starts here. Find ℓ_a, the first ℓ such that $p_\ell^\wedge = p_a^\wedge$, trying $p_a^\wedge$ = 400, 300, 200, 100, 500 mb in succession. If none found return. (Note that in (1) the output is preset to missing.)

(6) Integrate downwards from level ℓ_a calculating values of $T_\ell^\wedge$. Of the Flattery temperatures only the one at the anchor pressure, $T_{\ell_a}^\wedge$ is actually used. Given the upper level temperature $T_\ell^\wedge$ and the layer mean temperature $T_{\ell-1}$ we calculate the lower level temperature $T_{\ell-1}^\wedge$ for $\ell = \ell_a$, 2, -1. The calculation assumes T is linear in ℓn p and that T_ℓ is a mass weighted average. (See 5.1.3.)

(7) Integrate upwards. Here $T_\ell^\wedge$ and T_ℓ are known and $T_{\ell+1}^\wedge$ is calculated for $\ell = \ell_a$,L-1.

(8) Interpolate level temperatures $T_\ell^\wedge$ linear in ℓn p to obtain sigma layer values T_k. T_k is set to missing if $T_\ell^\wedge$ values above and below it are not available or missing. (There should be no missing values; see (1).)

(9) Determine sigma level heights $Z_k^\wedge$ by intergrating T_k hydrostatically. Original anchor for height integration is Z_*. If necessary due to a missing T_k reanchor to first guess $\tilde{Z}_k^\wedge$. In practice, missing T_k can only occur at top and bottom of profile. Normally, then, $Z_k^\wedge$ will be anchored to Z_*, since T_1 will usually be present.

Name: SETFG (subroutine)

Purpose: Initializes the bilinear interpolation by reading in the southernmost two latitudes of the first guess grid. Since data are sorted by latitude only two latitudes are needed at any one time.

Author: D. Norquist, SASC, 1980 - 1986

Documentation: R. Hoffman, AER, 1986

Referenced by: ASAP1

References: none

Commons used: CCONST, DCONST, FGFLDS

Arguments: none

I/O units: 1, 5

Description:

(1) Rewind units 1, 5.

(2) For latitudes 1 and 2, read $\tilde{T}$, $\tilde{U}$, $\tilde{V}$, $\tilde{R}$, $\tilde{P}_*$ for all longitudes and layers from unit 1. Similarly, read Z_* for all longitudes from unit 5.

Note: File structure is λ, k, ϕ, while /FGFLDS/ stores data by λ, ϕ, k.

4. Input/Output Usage.

Program ASAP1 uses units 1-8, 10, 11, INPUT and OUTPUT. Table 4.1 describes these files briefly. Table 4.2 lists the I/O activity in ASAP1.

Table 4.1

Files used by ASAP1. All files are either formatted (F) or unformatted (U).

Unit	Type	Description
1	U	Fine mesh first guess values for interpolation. Contains: $[(\tilde{X}_{ijk},\ i=1,I,\ k=1,K,\ X=\{T,U,V\}),$ $(\tilde{R}_{ijk},\ i=1,I,\ k=1,K_r),\ (\tilde{P}_{*ij},\ i=1,I)],\ j=1,J$ where I=360, J=181.
2	F	Unpacked GWE Level II data. See Norquist (1984), pp. 17-33.
3	U	Location information for observations. Contains: $[N],\ [\phi_n,\ \lambda_n,\ \underline{dsi_n},\ B_n,\ \underline{points_n}],\ n=1,N.$
4	U	Analysis grid first guess values. Contains: $[(\tilde{X}_{ijk},\ k=1,K,\ X=\{T,U,V\}),$ $(\tilde{R}_{ijk},\ k=1,K_r),\ \tilde{P}_{*ij}],\ i=1,I,\ j=1,J$ where I=61, J=62.
5	U	Fine mesh topography for interpolation. Contains: $[Z_{*ij},\ i=1,I],\ j=1,J$ where I=360, J=181.
6	U	Analysis grid values. Contains: $[(\tilde{X}_{ijk},\ k=1,K,\ X=\{T,U,V\}],\ i=1,I,\ j=1,J$ where I=61, J=62.
7	U	The sines of the Gaussian latitudes $[\sin \phi_j],\ j=1,J$ where J=62.

8	U	The residuals used by the analysis. Contains: [OBD(n,NW), NW=1,75], n=1,N.
9	-	Not used.
10	U	If this is the first analysis analysis in a sequence, this file contains the NMC EPE at the mandatory levels as a function of analysis grid latitude: $[(E_p(\tilde{X}_{j\ell}), \ell=1,L, X = \{Z,U,V\})], j=1,J$ where J=62, L=12. Otherwise, this file contains the EAE for height from the previous analysis: $[E_{a0}(\tilde{Z}_{ijk}), k=1,K]$, i=1,I, j=1,J, where I=61, J=62.
11	U	The EAE and the analysis corrections: $[(E_a(\tilde{X}_{ijk}), k=1,K, X = \{Z,U,V\}),$ $(x_{ijk}, k=1,K, x=\{z,u,v\})], i=1,I, j=1,J$ where I=61, J=62.
INPUT	F	Standard input device. Contains namelist DATIMOP.
OUTPUT	F	Standard output device. Contains printed output.

Note: In this table the contents of each record is described within square brackets ([ ]).

Table 4.2

I/O activity. All I/O activity is listed here except PRINTS to unit OUTPUT.

Unit	Activity	Occurences
1	Rewind	SETFG (1)
	Read	SETFG (2)
2	Open	ASAP1 (3)
	Read	ASAP1 (3), (6), (7), (8)
		MASTOR1 (2), (7)
		MASTOR2 (2), (7), (22)
		MASTOR4 (2), (8), (9), (13), (17)
		MASTOR6 (3)
	Rewind	ASAP1 (7)
	Open-Close	ASAP1 (3), (6), (7), (8)
		MASTOR1 (18)
		MASTOR2 (23)
		MASTOR4 (18)
	Close	MASTOR6 (19)
3	Write	ASAP1 (11)
4	Read	ASAP2 (1)
5	Rewind	SETFG (1)
	Read	SETFG (2)
		FG (2)
6	Write	ASAP2 (49)
7	Read	ASAP1 (13)
8	Write	ASAP1 (11)
10	Read	ASAP1 (14)
		ASAP2 (4)
11	Write	ASAP2 (49)
Input	Read	ASAP1 (2)

5. Methods

In this section we document certain methods which are used in ASAP1. This section of documentation is independent of the actual FORTRAN code. Some of these methods are used repeatedly in the code.

5.1 Conversions

5.1.1 Vector wind to components

Given wind speed $|\underset{\sim}{V}|$ and direction θ the eastward and northward wind components are given by

$$u = - |\underset{\sim}{V}| \sin \theta$$

$$v = - |\underset{\sim}{V}| \cos \theta$$

Note that θ is the direction the wind comes from. (See also Norquist 1986b, Eq. 23.)

5.1.2 Heights to temperatures hydrostatically (and vice versa)

The integrated form of the hydrostatic relationship is

$$(g/R)\ \Delta Z = \int_{p_\ell}^{p_u} T\ d\ell n\ p$$

where g is the acceleration of gravity, R is the gas constant for dry air, ΔZ is the thickness of the layer $(Z_u - Z_\ell)$ between pressure levels p_ℓ and p_u $(p_\ell > p_u)$, T is the temperature and p is pressure. Strictly T is virtual temperature. If T is linear in $\ell n\ p$, then

$$(g/R)\ \Delta Z = \overline{T}\ \Delta \ell n\ p$$

where $\overline{T}$ is layer mean temperature is given by $(T_u + T_\ell)/2$. A similar equation is given by Norquist, (1986b, Eq. 5).

5.1.3 Layer to level temperatures

A least squares procedure for converting between layer and level temperatures due to Flattery is described in detail by Norquist (1986b, Appendix A, pp 55-58.) As an alternative, if one level temperature is known,

then all other level temperatures may be inferred from a complete set of layer temperatures if some assumption is made about the functional form of $T(p)$ between the levels. If T is linear in $\ell n\, p$ then one obtains the method described by Norquist (1986b, Appendix D, pp 64–65). In brief, if $T = a + b\, \ell n\, p$ between p_ℓ and p_u, then we have

$$\overline{T} \int_{p_u}^{p_\ell} dp = \int_{p_u}^{p_\ell} (a + b\, \ell n\, p)\, dp$$

or

$$(p_\ell - p_u)\overline{T} = p_\ell(a + b(\ell n\, p_\ell - 1)) - p_u(a + b(\ell n\, p_u - 1))$$

$$T_u = a + b\, \ell n\, p_u$$

$$T_\ell = a + b\, \ell n\, p_\ell$$

which are three equations in the three unknowns a, b and either T_u or T_ℓ. E.g., if T_u is known, then

$$a = T_u - b\, \ell n\, p_u$$

$$b = (\overline{T} - T_u)\ (p_\ell - p_u)/(p_u + p_\ell[\ell n(p_\ell/p_u) - 1])$$

5.1.4 Humidity

Dew point, T_d, dew point depression $T-T_d$, specific humidity q and relative humidity r are all used in the analysis. These are related by the following expressions. (Dutton, 1976, Chap. 8):

$$r = e/e_s$$

$$e_s = e_o \exp\left[\frac{L_{\ell v}}{R_v}\left(\frac{1}{T_o} - \frac{1}{T}\right)\right]$$
$$= 6.11 \exp[19.9274 - 5443.3618/T]$$

$$e = e_s\ (T_D)$$

$$W = (1/\varepsilon)\ e/(p-e);\ e = \varepsilon Wp/(1+\varepsilon W)$$

$$q = W/(1+W);\ W = q/(1-q)$$

where

$$\varepsilon = (\text{molecular weight air})/(\text{molecular weight water}) = 1.61,$$

e is the vapor pressure, e_s the saturation pressure, and W the mixing ratio (i.e. the ratio of the mass of vapor to the mass of dry air). Similar equations are given by Norquist (1986b, Eq. 1-4 and 22) except that volume mixing ratio is used and the definition ε is reversed in Eq. 1-4.

5.2 Generic quality marks

We distinquish (a) quality indicators Q_I, which are read from the GWE Level II data, (b) generic quality marks, Q, which are used in the analysis selection procedures and (c) quality levels, Q_L, which are used in the buddy check procedures.

The quality indicators Q_I are described by WMO (1978), e.g. Table IV of Appendix A. Ordinarily, $Q_I = 0$ indicates no quality control check (QCC) was made and $Q_I = 1,2...$ indicate decreasing quality was determined during the QCC. However Q_I has different meanings for different data. In ASAP1 all Q_I are translated to Q, which always have the same meaning (see Table 5.1). Note if $Q(Z_i) < Q(Z_j)$ then Z_i is better than Z_j.

Table 5.1 Generic Quality Marks

Quality Mark	Meaning
0	Value found correct during QCC.
1	No QCC was made.
2	Value found erroneous during QCC, reconstituted value inserted.
3	Value found missing during QCC, reconstituted value inserted.
4	Value found missing during QCC, new value assigned.
5	QCC made, new value probably entered.
6	Value found suspect during QCC.
7	Value found erroneous during limits checks.
8	Value found erroneous during QCC.
9	Value missing.

The quality levels Q_L used in the buddy check are given by Norquist (1986b, pp 7-8).

$$Q_L = \begin{cases} Q+1 \\ 3(Q+3)+1 \\ 3(Q+3)+2 \\ 3(Q+3)+3 \end{cases} \quad \text{if } \underline{\text{type}} = \begin{cases} 1 \\ 2 \\ 4 \\ 6a \end{cases}$$

5.3 Buddy Check Boxes

The following procedure determines the buddy check box index B_n, given the latitude ϕ and longitude λ of observation (Norquist, 1986b, p.5):

(1) Determine the latitude band $i = 1, \ldots 18$ from SP → NP in 10° increments by $i = (\phi + 90)/10 + 1$. The center of the latitude band is then $\phi_c = 10i - 95$.

(2) Determine the number of boxes for this band as $n_i = 36 * \cos \phi_c$.

(3) Determine the longtitude index.

$$j = \lambda/\Delta\lambda + 1 \text{ where } \Delta\lambda = 360/n_i \ .$$

(4) Set $B_n = 100i + j$.

Note that, for the CRAY-1, λ and ϕ must be incremented by 0.001 to get reproducible results. This should have no effect since λ and ϕ are coded to hundredths only.

5.4 Vertical grid and interpolation

A sigma coordinate system is used. The interface value $\sigma_{\hat{k}}$ are given by $p_{\hat{k}}/p_*$ for k=1, K+1 . The layer thicknesses $\Delta\sigma_k = \sigma_{\hat{k}} - \sigma_{\widehat{k+1}}$ are defined as 0.075, 0.125, 0.150, 0.150, 0.125, 0.075, 6*0.050. In addition an assumed underground layer has $\Delta\sigma_u = 0.075$. Indexing starts with the ground k=1 and ends with the top of the atmosphere k = K+1. The layer σ_k values are given by

$$\sigma_k = [(\sigma_{\hat{k}}^{\kappa+1} - \sigma_{\widehat{k+1}}^{\kappa+1})/((\kappa+1)\Delta\sigma_k)]^{1/\kappa}$$

where $\kappa = R/C_p$ (Brenner et al., 1982, Eq. 32; Norquist, 1986b, Fig. 1).

Note that the vertical indexing for height is generally offset by 1. Thus, $Z_{\hat{k}}$ is the height at $\sigma_{\widehat{k+1}}$.

Vertical interpolation is generally linear in ℓnp; with data X_ℓ and X_u at p_ℓ and p_u we have

$$\frac{X-X_\ell}{X_u-X_\ell} = \frac{\ell n(p/p_\ell)}{\ell n(p_u/p_\ell)}$$

In ASAP1, this relationship is often put in point-slope form using the midpoint of the interval,

$$X=(X_\ell+ X_u)/2 + [(X_\ell- X_u)/\ell n(p_\ell/p_u)] \ (\ln p - 1/2 \ln p_\ell p_u)$$

5.5 Polar stereographic projection

For gridpoints with $|\phi_g| > 70°$ a polar stereographic projection is used for data selection, buddy checking and performing the analysis. Map factors are used throughout following Bergman (1979) although Dey and Morone (1985) suggest that for a polar cap the map factors are not necessary.

The conversion of (λ,ϕ) coordinates to (x,y) coordinates, in a system in which the positive x direction points from the pole towards Greenwich, is given by (Bergman, 1979, Eqs. 3.3-3.4)

$$m = 2/(1 + \sin(\pm\phi)).$$

$$x = am \cos\phi \cos\lambda$$

$$y = \pm\, am \cos\phi \sin\lambda$$

where m is the map factor, a is the earth's radius and the + (or -) corresponds to the Northern (or Southern) Hemisphere. The distance d_{ij} between two points indexed i and j is then given by (Bergman, 1979, Eq. 3.5)

$$d_{ij}^2 = \frac{1}{\bar{m}} [(x_i - x_j)^2 + (y_i - y_j)^2]$$

where $\bar{m} = (m_i + m_j)/2.$

In the coordinate system chosen for the projection, only the winds at 90°W are unchanged from the (λ,ϕ) system. The others must be rotated by (Norquist, 1986b, Eq. 6)

$$\begin{pmatrix} u' \\ v' \end{pmatrix} = - \begin{pmatrix} \sin\lambda & \pm\cos\lambda \\ \mp\cos\lambda & \sin\lambda \end{pmatrix} \begin{pmatrix} u \\ v \end{pmatrix}$$

where (u',v') is the wind in the stereographic projection and (u,v) is the wind in the (λ,ϕ) system. Again + (or -) corresponds to the Northern (or Southern) hemisphere. The reverse conversion is given by the transpose of the above rotation matrix:

$$\begin{pmatrix} u \\ v \end{pmatrix} = - \begin{pmatrix} \sin\lambda & \mp\cos\lambda \\ \pm\cos\lambda & \sin\lambda \end{pmatrix} \begin{pmatrix} u' \\ v' \end{pmatrix}$$

5.6 Coefficient of geostrophy

The coefficient of geostrophy G decouples the wind and height analysis in the tropics. Bergman (1979, Eq. 3.20) uses

$$\hat{G} = 1 - \exp\,(|\phi|/20)$$

while Dey and Morone (1985, Eq. B10) use

$$\tilde{G} = \begin{cases} 0 & 0 < |\phi| < 10 \\ [\cos\,(12|\phi|-300) + 1]/2 & 10 < |\phi| < 25 \\ 1 & 25 < |\phi| < 90 \end{cases}$$

ASAP1 uses (Norquist, 1986b, p14, and Fig. 2)

$$G = \begin{cases} \tilde{G}\,(\phi)\ \hat{G}\,(25) & 0 < |\phi| < 25 \\ \hat{G}\,(\phi) & 25 < |\phi| < 90 \end{cases}$$

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